The bearings box, with a full cast of cams, followers, weights and a friction-driven flagpole.

5 MAKING AUTOMATA MECHANISMS

The photographs and diagrams here should provide enough information to give a working knowledge of mechanisms, but the best way to understand what a mechanism can do for you is to make it or see it working. Only then can you really appreciate the action and relate it to the movement you wish to create. Indeed, the mechanism itself may suggest an idea for a piece. There is no substitute for actually handling and operating automata. One way of doing this is through buying one of the cheap wooden kits, or even paper ones, that are on the market. Peter Markey has designed a number of these, wonderfully simple examples of the automatist's art. Paul Spooner has designed the ingenious Camel Simulator (*see* photo above and drawing left).

To learn more about automata and mechanical toys, follow the step-by-step instructions of how to make the mechanisms and discover what they do. All the main movements for making automata are described here. Their mechanisms are designed to be assembled and dismantled, by friction fit, on to the bearings box, which houses the shaft. Clearly, there are many tiny bits and pieces to make and assemble, and it is important not to muddle them up, so they have been coloured for identification. Also each piece, even down to the last washer, is numbered, to correspond to a section in the 'box of mechanisms' that houses them. For the plans for making the

ABOVE: There are a number of simple kits available that are ideal for learning about mechanisms. Most were designed by Peter Markey and made by Eric and Alison Williamson, who also designed and made 'The Caterpillar'. 'Anubis Riding Simulated Camel' is by Paul Spooner and marketed by Cabaret Mechanical Theatre.

FAR LEFT: Plan for the Camel Simulator kit, designed by Paul Spooner for CMT.

box, *see* page 109. As the sections are built to the interior height of the box, the pieces are kept safely within them.

For simplicity, **the plans show wood thicknesses in millimetres only**. For imperial/metric conversions, *see* the table on page 116.

The bearings box, crank handle and shaft, which appear on Plan 1, are basic mechanisms that are used throughout, but they are not reproduced on every plan. Similarly, the plinth, which appears on Plan 8 for four-bar-linkage, is too large to reproduce more than once. Therefore, when making the ratchet (Plan 10), pin wheels (Plan 13), and the friction-driven pole (Plan 14), you should refer to Plan 8 for making the plinth.

The bearings box and shaft and crank handle.

BEARINGS AND SHAFTS

The bearings box acts as a proscenium throughout for the mechanical activity provided by a cast of cams, cogs, levers, ratchets and wheels. As on a stage, where actors do not all come on at once, the mechanical participants will make their appearances separately or together, as the performance dictates.

A star in the troupe of mechanisms is surely the crank pin, with its eccentrically positioned pin on the wheel attached to the shaft. It plays a pivotal role in the four-bar linkage, the bell crank and all ratchets, including the Geneva wheel. The function of the bearings box is to support, at either end, a rotating shaft that plays a more ubiquitous, though less showy, role than the crank pin.

For light wooden automata and mechanical toys, you need to drill a hole slightly larger than the diameter of the shaft in the two sides of the bearings box, temporarily bonded together. This ensures accuracy when the dowel shaft rotates in the bearings.

Shafts can be made from piano wire or even coat hangers, which can be bent to make crank handles. Brass tubing can add strength to the bearings.

Rotation is not the only motion for a shaft, which can also move up and down in its bearing. For this reason, the top of the bearings box is much thicker than the sides. It allows the vertical bearing to contain the moving shaft, discouraging drift or jamming.

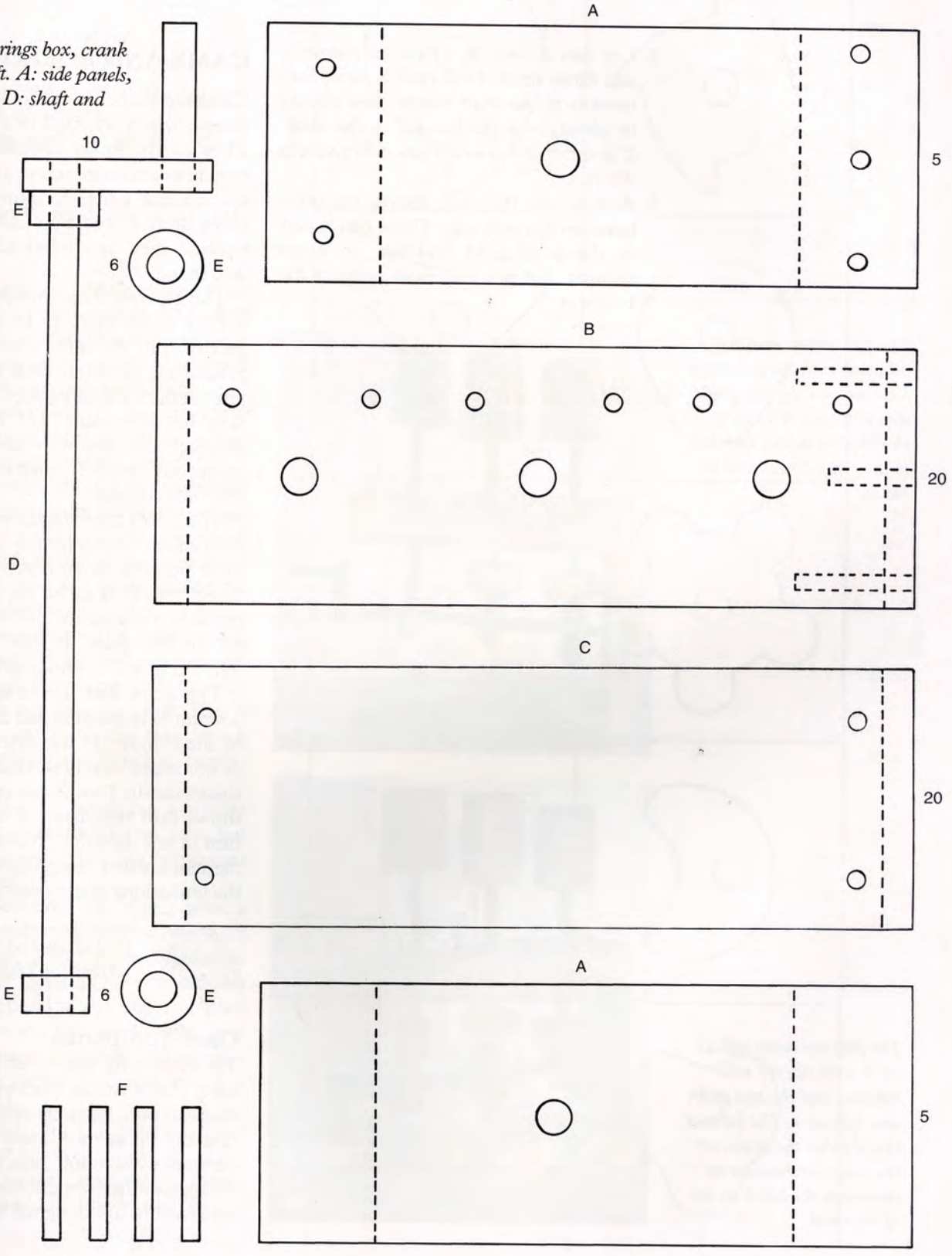
Making the Bearings Box

1. Cut two side panels A, from 5mm thick plywood, temporarily bonding them. Then drill a hole to fit a 5mm dowel shaft, so that it can move freely, not too loosely or snugly, within the bearing. Separate the sides and sand off.
2. Cut the top B and base C, from 13/16 × 1¾in (20 × 44mm) baton. Drill holes, as indicated on Plan 1, right through the top, B. Drill holes to a depth of 17mm in the underside of the base B. The large holes are bearings for pin and roller followers (*see* page 80, on cams and followers). The small holes will house pegs for fixtures with a friction fit.
3. Now glue the two sides A, to support the top B, and to rest on the base C. Ensure that all is square otherwise the shaft will not work smoothly in the bearings.
4. Cut the four pegs F for the base and the plinth (*see* Plan 8) for four-bar linkage.

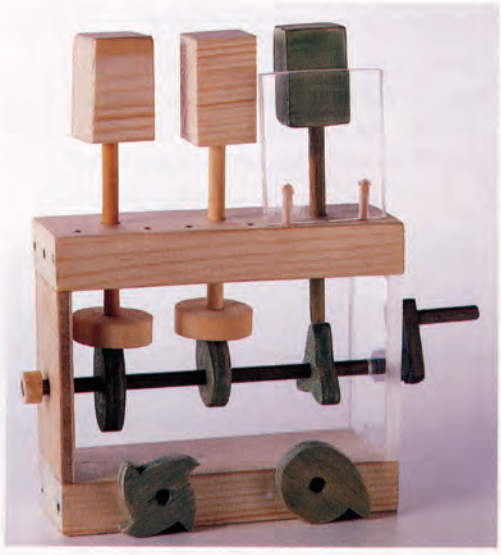
Making the Shaft

1. Cut a long and a short dowel for the shaft D and crank handle. Drill two holes into the 5mm × 10mm stripwood for them.

PLAN 1
Making the bearings box, crank handle and shaft. A: side panels, B: top, C: base, D: shaft and crank handle, E: dowel collets, F: pegs.
NB: Wood thickness is shown in millimetres throughout.



2. Cut two dowels E, 12mm in diameter and 6mm thick. Drill central holes into these to fit the shaft tightly. One should be glued, with the handle, to the shaft. The other serves as a friction-fit collet at the end.
3. Ensure that the shaft moves smoothly between the bearings. These can shrink in damp or cold weather, so allow enough, but not too much, play in the bearings.



The five green cams will all work with the green pin follower and the two plain disc followers. The perspex shield gives added stability to the pin follower and its block.

The five red cams will all work with the red roller follower and the two plain disc followers. The perspex shield takes the strain off the roller mechanism by steadying the block on top of the shaft.

CAMS AND FOLLOWERS

Cams are shaped pieces of wood, metal or plastic, which are fixed to a rotating shaft. They can be linear or rotary. The rotary type is much more usual, changing rotary motion into either reciprocating or oscillating motion. Some are called lobed cams because they have lobes added on to the disc shape.

The follower hugs the profile or radial surface of the cam. It does this either by gravity or by the aid of a spring. The more precise the follower, such as a roller or a pin follower, the more accurate the projection or movement will be. Therefore, although disc followers should never jam (never say 'never'!), they follow cam profiles only roughly.

The rotary cam shown on the cam templates plan (*see* opposite) is probably the most popular, since it can be cut from a dowel rod. It is called the circular eccentric cam, because the disc is fitted off-centre on the shaft. It lifts and drops the follower in one continuous movement.

The shape and size of cam dictates the amount of movement and distance covered by the follower. It also determines whether or not it can turn both clockwise and anticlockwise. In Plan 2 (*see* opposite), which shows cam templates, A and B can only turn in one direction. It is most important, therefore, when designing a piece, to know the limitations of the cams you wish to use.

COLOUR AND NUMBER THE PARTS

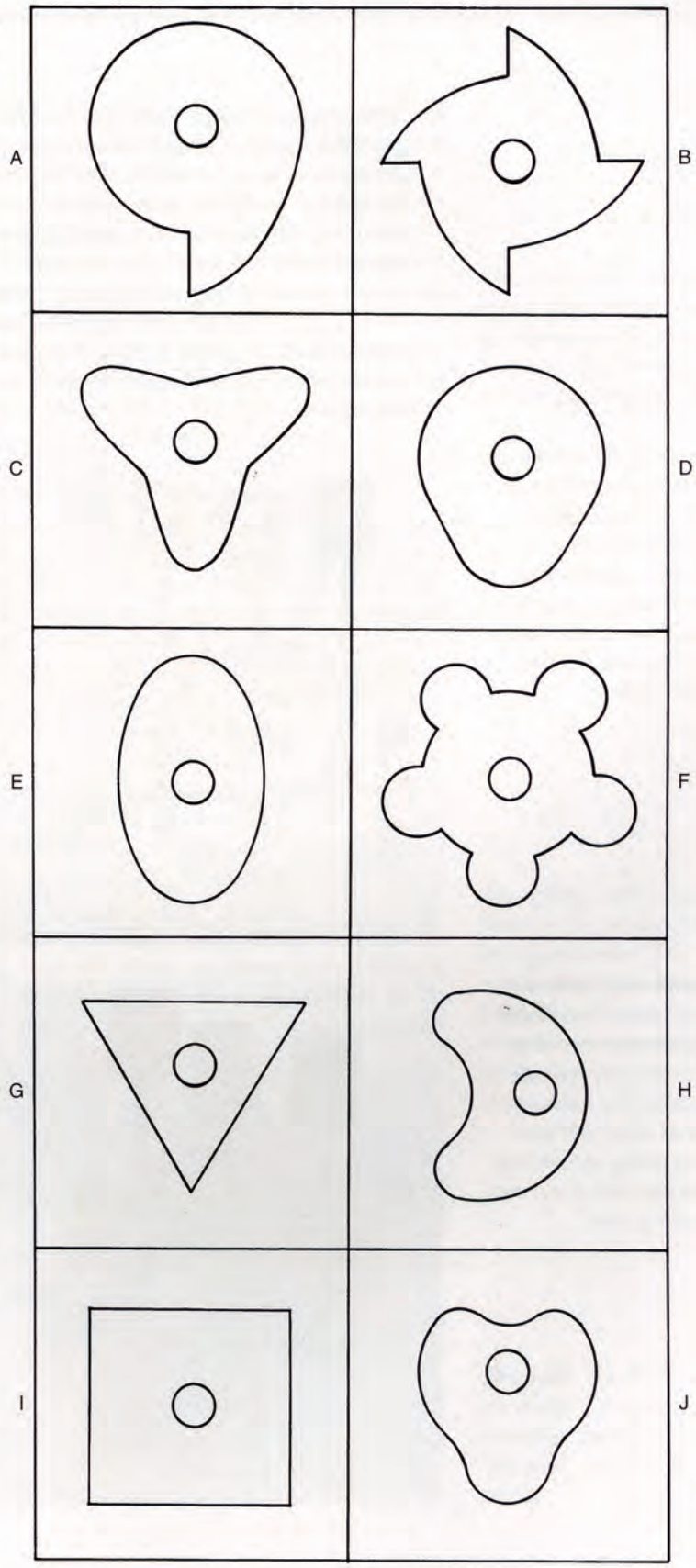
Cam Templates

The cams in the photos left give a good variation of movement. Each provides activities that can only be really appreciated by cutting the 8mm thick cams from plywood, temporarily bonding them to the shaft, and seeing how they work. Remember that these mechanisms are designed to be dismantled

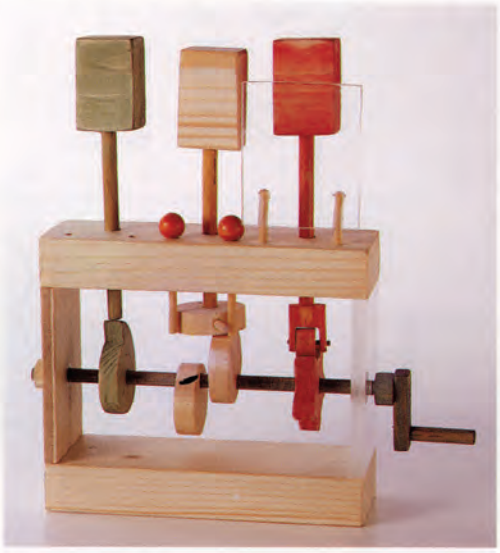
PLAN 2
Making cam templates. A, B, C, D and E will work with a pin follower. F, G, H, I and J will only work efficiently with a roller follower. All cams work with disc followers.

so that they can be fixed into or on to the bearings box.

1. The snail cam (A) produces one event per revolution. Positioned on the shaft as a figure nine, facing the crank handle, it will only turn anticlockwise. Positioned as a six, it will turn only clockwise.
2. The four-lobed cam (B) produces four events per revolution, bobbing up and down. It can turn only clockwise.
3. The three-lobed cam (C) will work with a pin follower, but the bearing must not be too wide for the pin, or it will jam. A perspex shield, or any smooth-surfaced panel or bar, used as a guide against the block, will solve that problem.
4. The pear-shaped cam (D) produces an up and down motion with a dwell, or pause, period. For more than half the cycle the follower does not react. This is unlike the eccentric circular cam, which gives a continuous oscillating performance.
5. The oval cam (E) produces a similar action to the eccentric circular cam, but at twice the speed, providing two events per revolution.
6. The five-lobed cam (F), which gives a staccato up and down motion, can only work efficiently with a roller follower or a disc follower. A pin follower could jam on the lower parts of the radial surface. Only the roller can accurately and smoothly manage the peaks and troughs of the cam's profile, with the aid of a perspex shield.
7. The triangular cam (G) operates best with the roller follower. Those sharp little corners, unlike those of the three-lobed cam, would in time be dulled.



8. The crescent cam (H) produces a pleasing rhythmical and bouncy movement. It is important that the bearing for the roller follower is not too wide, or jamming will occur. Once again, a perspex shield would solve the problem.
9. The square cam (I) will actually work with a pin follower but, as with the triangular cam, it is a smoother ride with the roller, with less friction on the corner.



The central disc follower is fitted with a small dowel pin. It is checked from rotating too far by two other pins. The circular eccentric cam on the right lifts and rotates the outer edge of the disc follower, anti-clockwise.

The central disc follower is raised on its outer edge by the circular eccentric cam on the left, rotating clockwise. The mechanism serves as both cam and friction drive, moving the follower up and down and from side to side.

10. The radii of this cam (J) are dipped and raised as if bites have been taken out of the disc. The radial surface provides dwells in the action. It has a pretty movement, reminiscent of a trotting rider.

COLOUR AND NUMBER THE CAMS

Working in Wood

The friction drive mechanism cannot be as efficient as a metal or plastic formed bevel gear, but for the purpose of making fairly simple automata and mechanical toys, the results can be perfectly adequate and satisfying, both aesthetically and mechanically. If a more positive performance than friction movement is required, pin wheels could help (*see* page 101, for details on gears), although they will take up more space in your design.

Working in wood is very different from working in metal. The tolerances are so much broader and the drill and the saw can 'drift' in wood. Use sharp drill bits and blades to counteract these negative forces. It is essential to test-drill bearings. If the hole is too generous, the follower may bob around like a cork at sea! One remedy is to wet the bearing, in order to shrink it. This trick is especially useful to tighten stops used at the end of shafts, if using friction fit. Conversely, to facilitate movement in a bearing, a little candle grease rubbed into it and on to the follower can reduce friction. Small party-cake candles are ideal for this.

In extreme temperature conditions, bearings can tighten, so pieces in storage should be insulated with bubble-wrap. A protective cardboard box will also help.

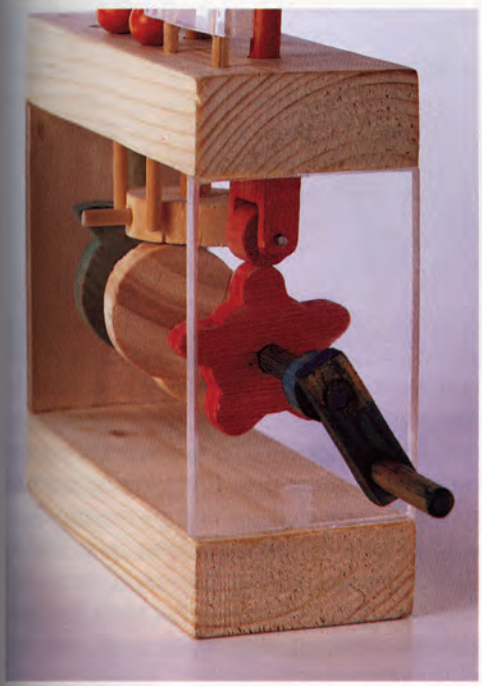
It may be necessary to use a panel of perspex or some other smooth-surfaced material to steady a follower in too wide a bearing. A horizontal bar placed against the top of the follower block will have the same stabilizing effect. If you can incorporate this

ergonomically in your design, so much the better.

Wood is an imprecise material, and the amount of 'play' in a wooden bearing is critical. Even after test-drilling, the dowel shaft of the follower in the bearing may not work 'on the night'. It is frustrating and you may be tempted to drill too wide a hole to allow ease of action. That can lead to problems, with the follower jamming on certain cams. Using a panel or bar, either openly or artfully concealed, can overcome these difficulties.

If your design does not allow for such problem-solving devices, remember that the deeper the follower's channel in the bearing, the better it will perform.

The roller follower is at the lowest point on the profile of the pentagonal cam. There are five events per revolution, or cycle.



The roller is at the highest point on the profile of the pentagonal cam. The crank handle has moved from 20 to 25 past the hour, being one event in the cycle.

The Roller Follower

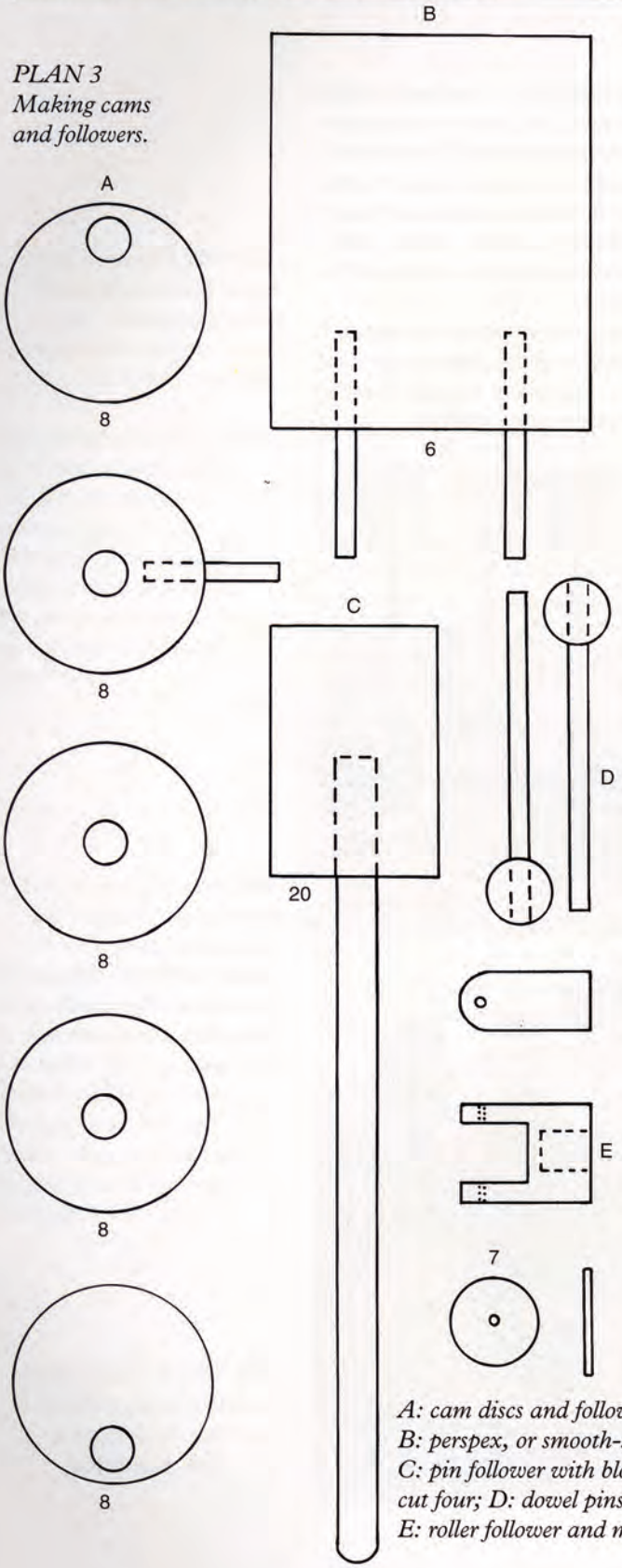
The free-running bearing or roller, fixed on the end of a pin follower, will facilitate tracking cams that have eventful profiles. An empirical approach will determine when and where you should use it. In most simple automata, it is rarely seen, because the cams are uncomplicated. It is only when the follower needs to track the cam's profile accurately that the device can play a useful role in relaying precisely the cam's message to the follower. It also reduces friction, which might be an important factor in the design of the piece.

Making Cams and Followers

1. Cut five discs A, from 1⅛in (28mm) dowel. Drill holes as indicated, to fit tightly on dowel rods. The middle three

This roller is to be fixed to the end of a pin follower. It smoothes the path on a cam with an eventful profile.

PLAN 3
Making cams and followers.



A: cam discs and followers; B: perspex, or smooth-surfaced panel; C: pin follower with block weight; cut four; D: dowel pins and beads; E: roller follower and mechanism.

are disc followers, one with a restraining pin to prevent it from swivelling too far. The outer two are eccentric cams, which fit on to the camshaft.

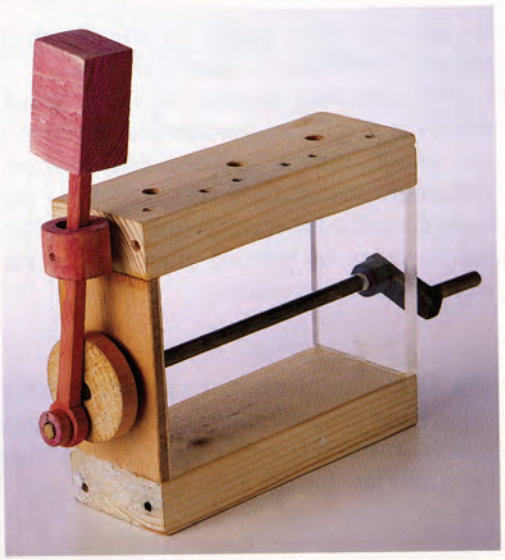
2. Cut a perspex or smooth-surfaced panel B. Drill holes in the base to receive the two small dowel pins.
3. Cut four large dowel pins, rounding their ends. Cut four blocks C, drilling central holes in their bases to fit on the dowel pins. These blocks are weights for the followers. One is stained green, one red, and two are plain. They fit into the bearings on top of the bearings box.
4. Cut five thin dowel pins 3mm (⅛in) as indicated. Drill a central hole in the side of the disc to receive the shortest pin. Fit the two shorter pins into the base of panel B. The longer dowel pins D fit into two small wooden beads. These are placed, vertically, in front of the central disc follower, with the pin, on top of the bearings box.
5. Assemble the roller follower E (*see* the photo). Drill a small central hole in the roller. A thin piece of piano wire, or a panel pin, cut to size, will serve as the pin that holds the roller in position. Drill the bearing before you cut out the central part of the device, in case it collapses. Ensure that the dowel roller fits, but not too snugly.
6. Colour and number the parts.

CRANKS

A crank can be a handle that turns a shaft or, indeed, a shaft that turns a handle. The crank pin, which plays such a major role in the making of automata, has a small 'handle' in the form of a pin fixed near the outer edge of the disc. This, when attached to a rod, moves it up and down and from side to side. The mechanism is known as the crank slider and has great versatility (*see* the three versions – slotted bearing, circular bearing and using pegs – in the photos opposite).

FAR LEFT: The crankshaft turns the crank pin, which raises and lowers the weighted rod, backward and forward, within a fixed slotted bearing. This is called a crank slider.

The crank has converted rotating motion into reciprocating motion. The amount of vertical movement can be seen.



FAR LEFT: The rod at its highest point is moving within a fixed circular bearing.

There is less lateral movement in the circular bearing than in the slotted bearing.

In the slotted bearing version, in an open narrow box without a base, the rod rides, up and down, within the slot. It is a fairly vigorous, hammering movement.

The circular bearing version confines the lateral motion to a gentle nodding. The distance travelled and the height gained by the rod are exactly the same as with the slotted bearing. The amount of play within the circular bearing determines the degree of lateral action.

The third version of the crank slider allows for experimentation with the use of pegs. The lower the pegs are placed on the peg board, the greater the side-to-side movement. This version combines the actions offered by the other two and, at its most active, evokes the image of a boat bobbing

ABOVE: The crank slider allows sideways movement to increase when the pegs are fixed low, and to decrease when they are placed high.

ABOVE RIGHT: The movement suggests a boat bobbing up and down on the sea.

on the sea. This might be one example where a mechanism suggests an idea.

The common feature of these crank sliders is a rotating motion converted, by the crank, into a reciprocating motion. Although the rod moves vertically, the same distance for each version, it is the different types of bearing that govern the side-to-side movements.

Making Crank Sliders

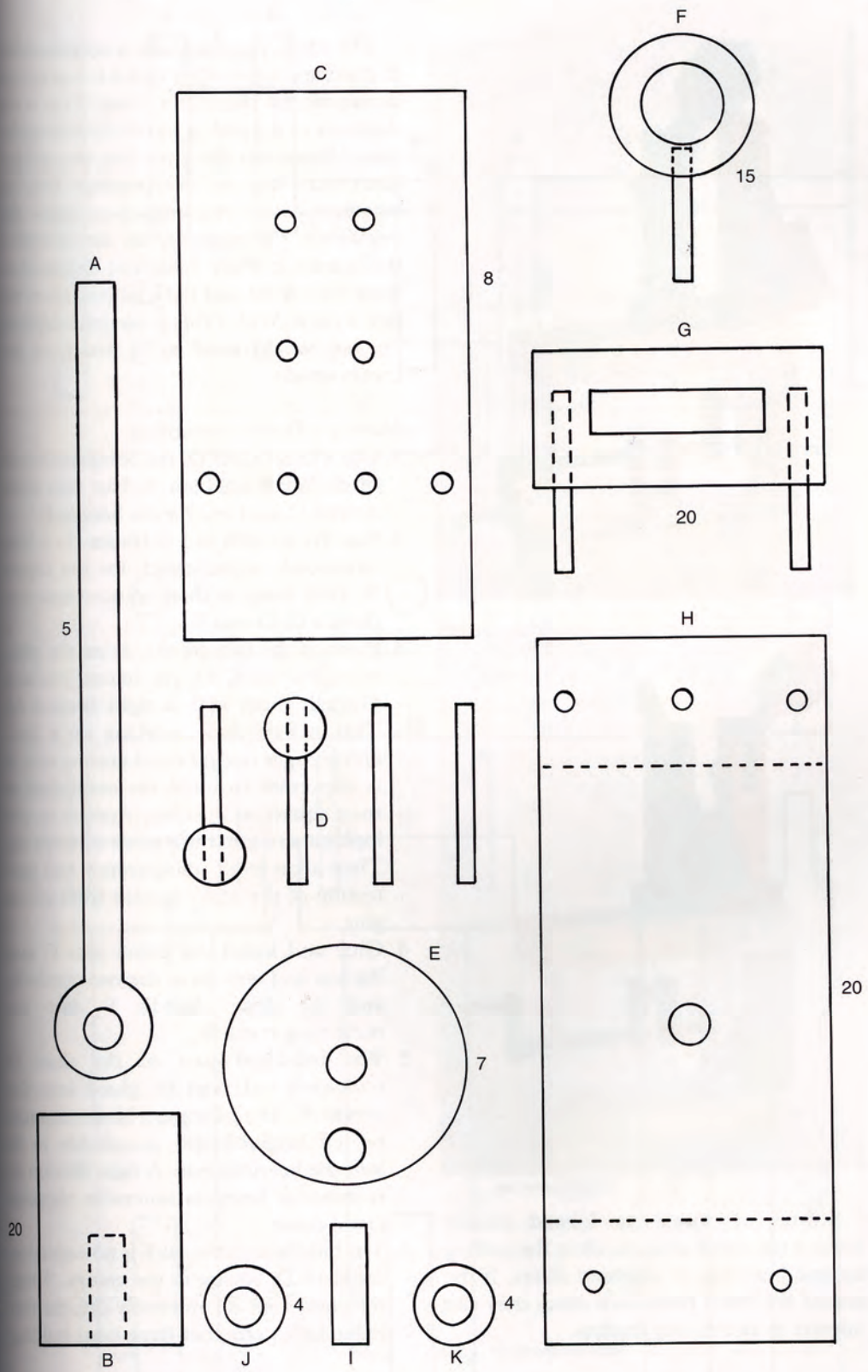
The following instructions are for making three types of crank slider to operate, separately, on the side panel H of the bearings box (*see* Plan 4, page 87).

1. Using ply or stripwood, drill a hole at the base of rod A. Cut out the rod, with the drilled hole, and chamfer the edges.
2. Cut the block B, and drill a hole in it to receive the top of rod A, which is, of course, square.
3. Cut out the peg board C and drill holes to accommodate 3mm (⅛in) dowel pins, and pegs D. The two pegs on the left, with wooden beads as heads, will fit into any of the central holes. The two pins on the right are glued, flush with the surface, into the outer holes at the base of the peg board. This enables you to fix the board on to the side panel H, by inserting the pins into the two outer holes, at the top.
4. Cut out the disc E for the crank pin and drill holes as indicated. Cut and glue a dowel pin I, in the outer hole. Cut the dowel collet J for the crankshaft and drill a hole so that it will, by friction, fit on to the end. Cut a dowel washer K for the crankshaft and drill a large hole to fit loosely. The washer compensates for the thickness of the peg board and bearings. It enables rod A to work smoothly and straight, at 90 degrees.
5. Cut the circular bearing F, from ⅞in (22mm) dowel rod, or from ply, and drill a central hole in the side to receive 3mm (⅛in) dowel pins. Drill the large central hole, which is the bearing for rod A. Glue the dowel pin into position, ensuring that it does not encroach on the bearing's aperture. This little wooden 'O' fits, by friction, into the middle hole in the side panel H.
6. Cut the slotted bearings block G, with a guide slot for rod A to move in. This should be filed, if necessary, to ensure that there is enough, but not too much, play in the bearing. Drill 3mm (⅛in) holes to accommodate the dowel pins and glue them into the block. These must fit, by friction, into the outer holes at the top of the side panel H.

COLOUR AND NUMBER THE PARTS

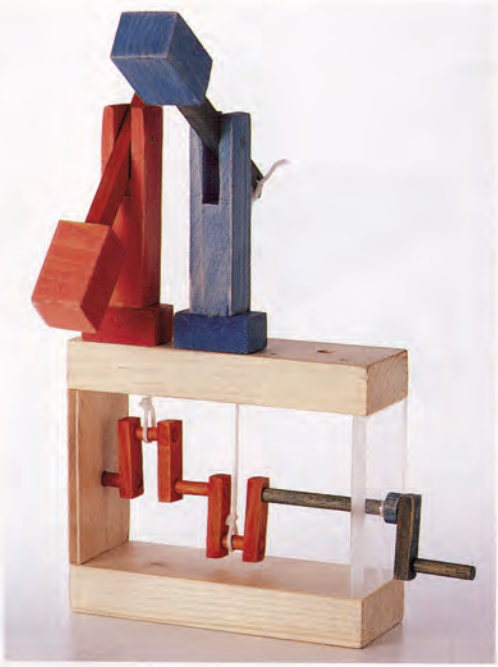
The Double Crankshaft

As with most rotating shafts, a crankshaft is supported by bearings at either end. Sometimes, if the shaft is long, more bearings in the middle may be required. Additional cranks can be added to the shaft, but they take up more space than cams. However, they do more powerful work.

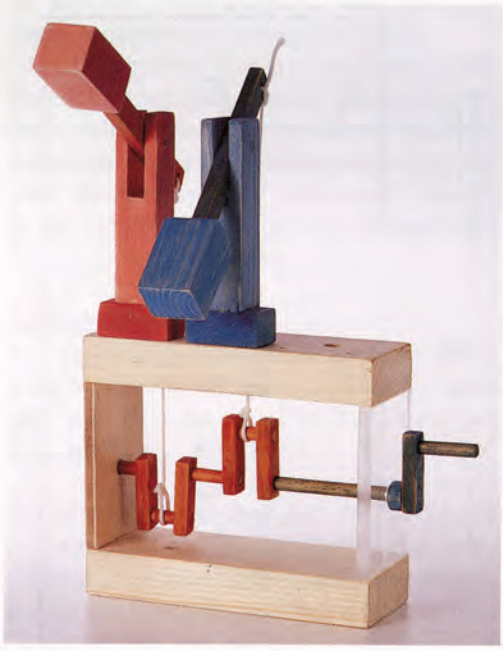


PLAN 4
Making crank sliders. A: rod; B: block; C: peg board; D: pegs; E: crank disc; F: circular bearing and peg; G: slotted bearing and pegs; H: side panel; I: dowel pin; J: dowel collet; K: dowel washer.

As the red lever is down the crank beneath is up. While the blue lever is up, the crank below is down.



It can be seen that the crank merely follows the rotation of the handle. As the red lever is up the crank beneath is down. While the blue lever is down the crank below is up.

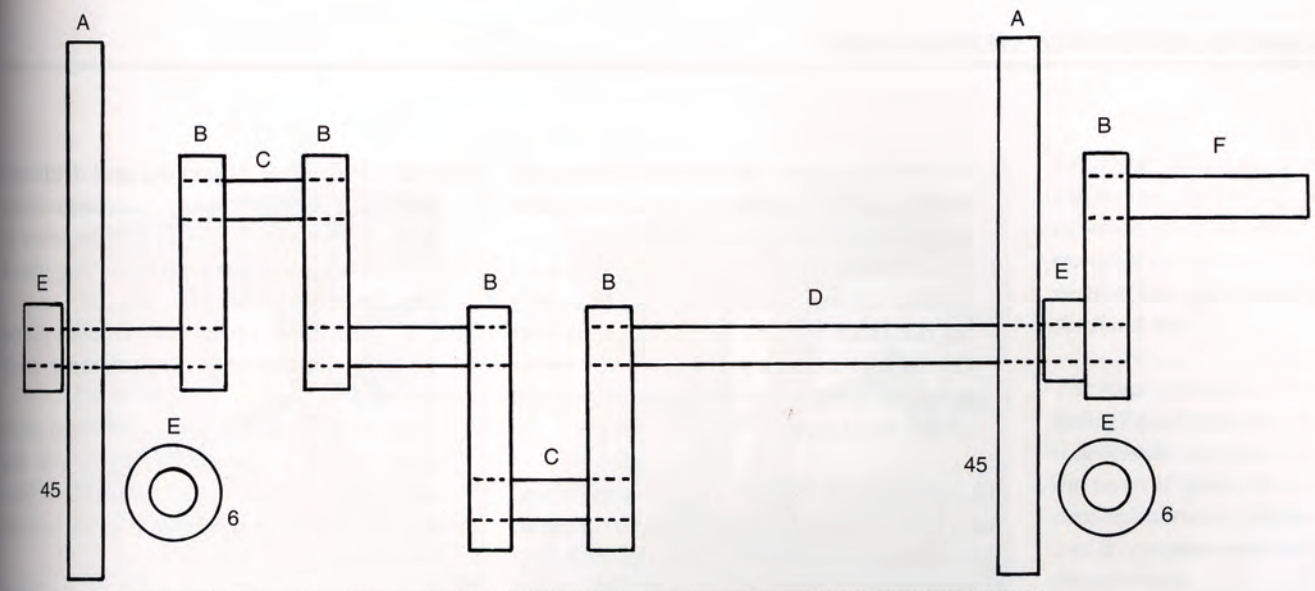


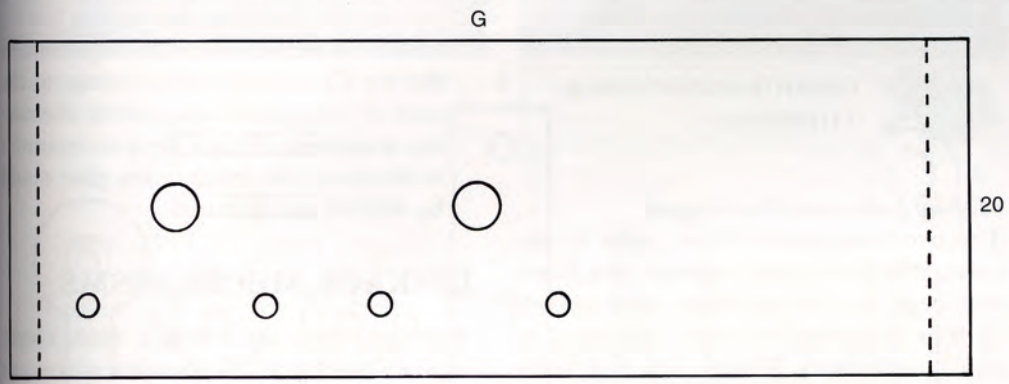
Strings or wires are looped loosely around the crank pins, to allow the pulling up and lowering of weighted levers. If the cranks are offset from each other they can operate in alternating rhythm.

The most important thing to remember in making crankshafts is that it is essential to determine the *throw* of a crank. This is the diameter of the path it travels in one revolution. Unless you allow for this, the mechanism may jam in the bearings box, or whatever device you employ to house the crankshaft. For example, the dimensions of the cranks in Plan 5 are not designed to work with front and back panels, since the box is open. With a closed box, the depth of the box would need to be wider, or the cranks smaller.

Making a Double Crankshaft

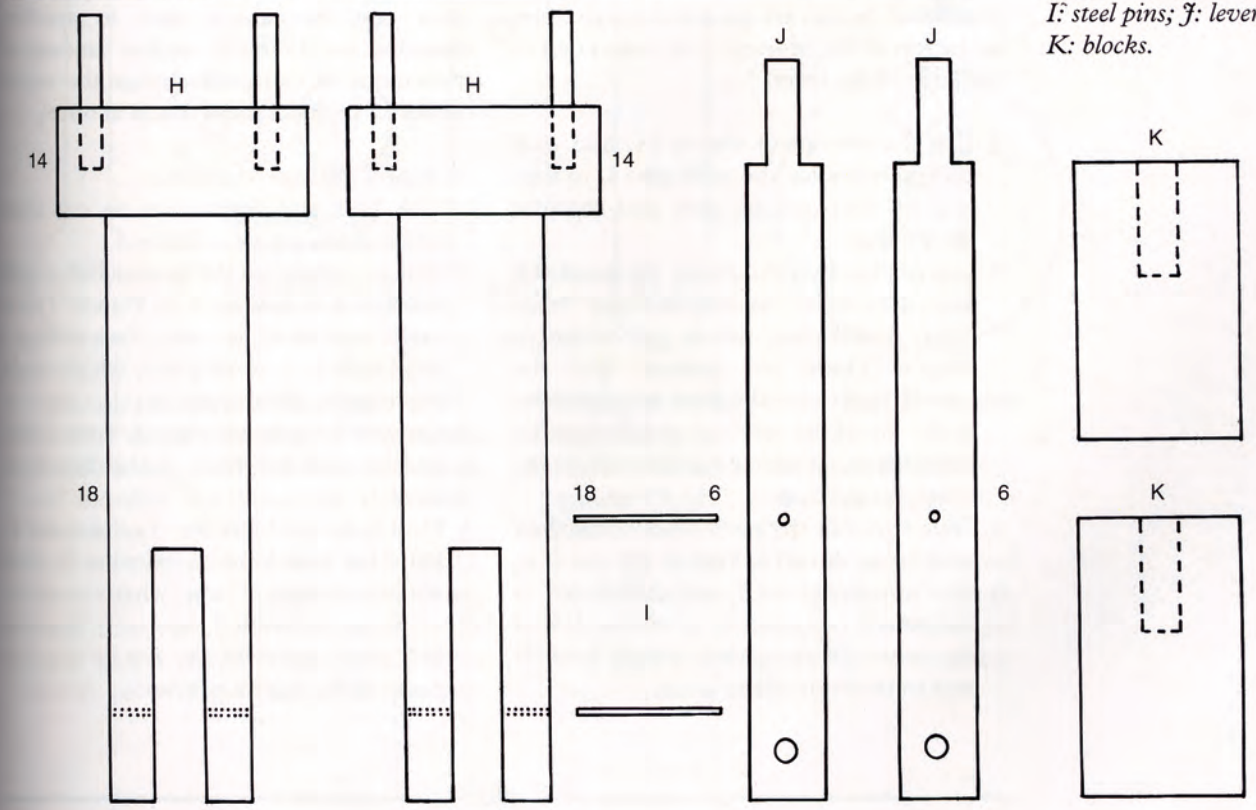
1. Cut a long dowel D, the complete length of the shaft on Plan 5. Cut two short dowels C, and one for the handle F.
2. Cut five lengths of 5 × 10mm (3/16 × 3/8in) stripwood, as indicated, for the cranks B. Drill holes in them to accommodate dowels C, D and F.
3. Position the two cranks, as on the plan, with the shaft, as yet uncut, running through them with a tight friction fit. This is best done working on a grid, graph paper or calibrated cutting mat. It is important to build the crankshaft as truly square as possible. Acetate or cellophane are good materials to work on. They allow both transparency and protection of the grid's surface from excess glue.
4. Glue and insert the crank pins C into the top and bottom of the two cranks B, and the dowel handle F, into the remaining crank B.
5. The left-hand part of the shaft D (coloured red) can be glued into the cranks B. The blue part, however, must be left unglued and detachable to fit into the bearings box. A tight friction fit is essential here, as otherwise slippage could occur.
6. The handle assembly B/F is now glued to the shaft D, square to the cranks. When the crankshaft is completely dry, the two redundant parts that have been holding





ABOVE: PLAN 5
Making the double crankshaft. A: side panels; B: cranks; C: crank pins; D: shaft; E: dowel collets; F: handle.

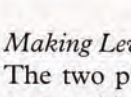
LEFT & BELOW: PLAN 6
Making levers and pivot stands. G: top of bearings box; H: pivot stands; I: steel pins; J: levers; K: blocks.



everything square are cut out. Strings or wires can now be looped loosely around the crank pins and fixed in position.

7. The two dowel collets E are cut from 12 × 6mm dowels and drilled to fit tightly on the shaft D. One is glued to support the handle assembly B/F, and the other serves as a tight friction stop for the end of the crankshaft.

To fit the crankshaft into the bearings box, insert the blue half through the bearing in the right side panel A. Put the red half through the bearing in the left side panel A, and join them together, inside the box.



COLOUR AND NUMBER THE PARTS

Making Levers and Pivot Stands

The two pivot stands H are made in two parts, which are glued together and fitted, with pegs, into the top of the bearings box G. The weighted levers J/K are fixed by pins into the slots. Strings, attached to the crankshaft below, are passed through holes in the top of the bearings box G and tied to the ends of the levers J.

1. Cut the two pivot stands H, and drill central holes for the steel pins I, to friction fit. Cut out the slots and chamfer their edges.
2. Cut out the two plinths for the stands H, and drill holes to receive four 3mm (⅛in) dowel pins, which can be cut to length. These are inserted into the plinths to fit into the four smaller holes in the top of the bearings box G. Careful registration, in matching the pegs to the holes, is required.
3. Glue together the pivot stands and their plinths, as shown in Plan 6.
4. Cut out the levers J, and drill holes as indicated, one for the steel pin I, and the other for the string, which is to be tied to the ends of the levers J.
5. Cut out the two blocks K, and drill central holes in their bases to accommodate the square-ended shafts of the lever J. These square pegs can now be glued into the round holes.
6. Cut 2mm (1/16in) steel pins I, from piano wire, or use panel pins with their ends cut off and filed.
7. Place the weighted levers J/K into their slots in the pivot stands H. Push the steel pins I through the channels, to friction fit. They should work freely within their slots.
8. With the complete assembly in position and the crankshaft in the bearings box G, feed the strings through the large holes in the top G. Loosely tie the strings to the ends of the levers J, and test the alternating movement. If there were no intention to dismantle the mechanism, glue would be dabbed on the knots.

LINKAGE MECHANISMS

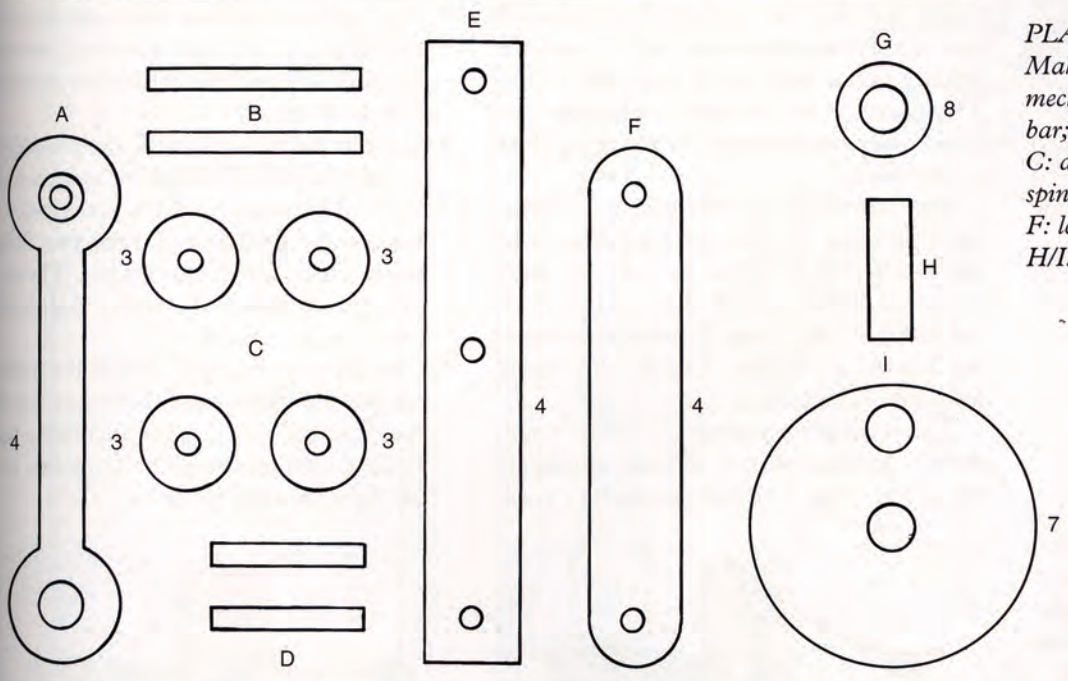
A linkage can be made from a crank, a lever or a connecting rod. It transfers movement from one mechanical part to another, changing its direction or the amount of movement. It can even change the way it moves ... or do all these things at once!

Making a Linkage Mechanism

1. The bars and levers can be cut from either 4mm ply or stripwood.
2. Before cutting out the linkage bar A, drill holes in it as indicated on Plan 7. This is easier and more accurate than drilling a large hole in a small piece, which might move in the drilling process.
3. Cut two long dowel pins B, 3mm (⅛in), and cut and drill holes in the dowel collets C.
4. Drill holes and cut out the fixed bar E. Glue the two long dowel pins B, flush with its surface. These, when the mechanism is assembled, are to fit into the two outer holes at the top of the side panel of the bearings box.

FAR LEFT: When the crank pin rotates, the linkage bar to which it is attached transfers movement to the vertical lever pivoting on the fixed bar.

The rotary motion of the linkage bar turns into a side-to-side movement of the vertical lever. Half a turn will thrust it forward, and a complete turn will draw it back.



PLAN 7
Making a linkage mechanism. A: linkage bar; B: dowel pins; C: dowel collets; D: dowel spindles; E: fixed bar; F: lever; G: dowel collet; H/I: crank disc and pin.

5. Drill holes in, and cut out, the lever F.
6. Cut the crank pin disc I, from either dowel or ply. Drill holes as indicated, cut and glue the dowel pin H into the outer hole.
7. Cut the two short dowel spindles D, 3mm (⅛in), and insert one of them, freely, through the vacant hole in the fixed bar E. Secure this with a tight dowel collet C, adjacent to the two long, projecting dowel pins B, in the fixed bar E.
8. Place one end of the lever F on to the spindle D, and secure this joint with a tight dowel collet C.
9. Place the linkage bar A on top of the lever G, inserting a dowel spindle D through them both. Lock the spindle at either end with tight dowel collets C, ensuring that the parts move freely.

10. To assemble the mechanism, insert the fixed bar E, with the two dowel pins, into the side panel of the bearings box. This should have holes, already drilled, to receive the pins, as in Plan 1B. Fix the crank pin tightly on to the shaft, attaching the linkage bar A to it and sealing it with dowel collet G.

COLOUR AND NUMBER THE PARTS

The Four-Bar Linkage Mechanism

Also known as the quadratic-crank mechanism, the four-bar linkage mechanism is also sometimes referred to as the three-bar linkage, since only three bars are visible. The fourth is an invisible, stationary bar, which connects the lever in the pivot block to the crank.

Whether three- or four-bar, the mechanism consists of four links connected by pin joints; the first link has already been mentioned; the second link is the crank; the third is the coupler, which connects the crank, or linkage bar, to the fourth link, which is the lever.

The linkage employs a crank slider device (*see* page 86), with pegs to contain the linkage bar. The bar can make a complete revolution while the lever moves from side to side, translating rotation into oscillation.

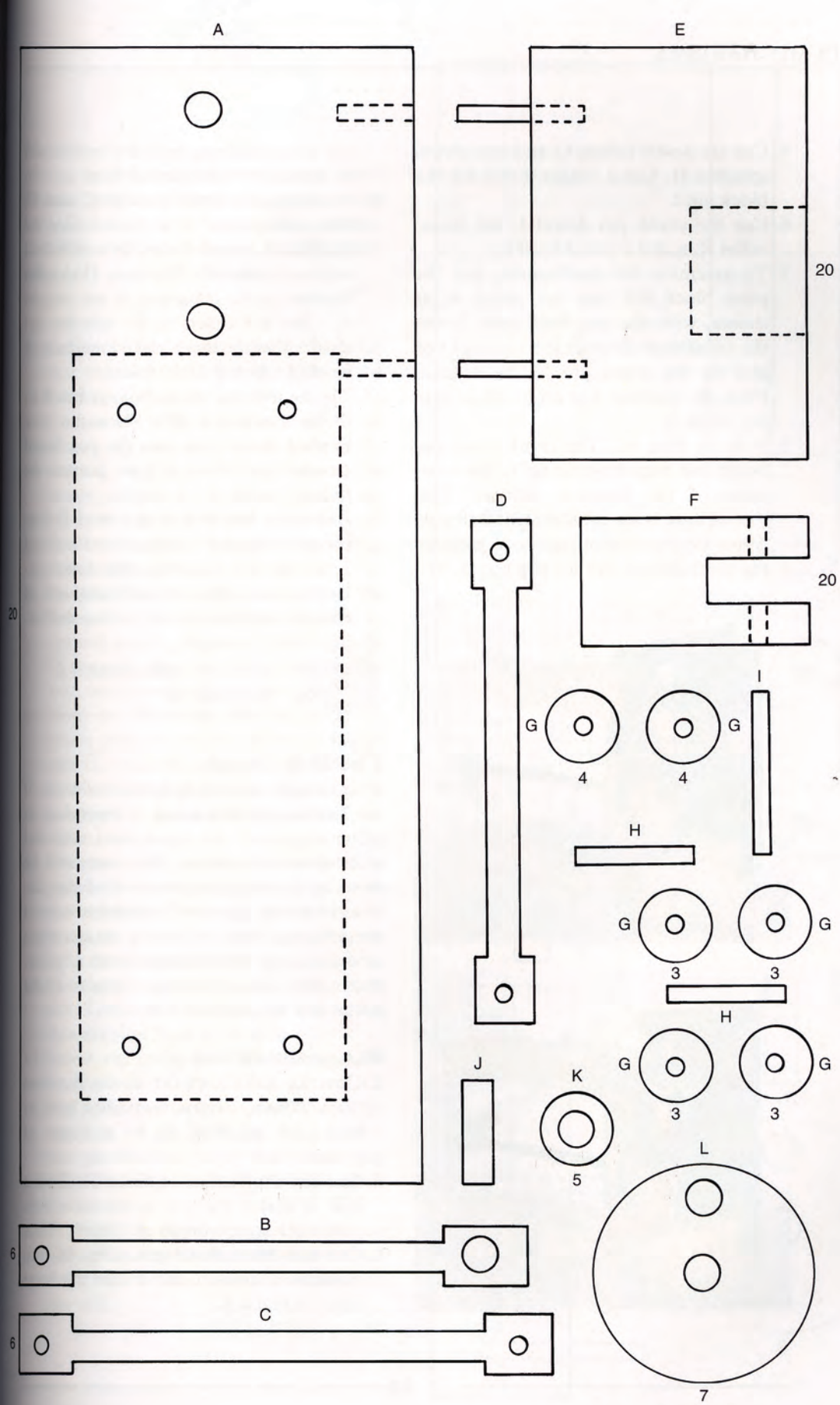
Making the Four-Bar Linkage Mechanism

Unlike the previous mechanisms, the four-bar linkage needs an extension of the dimensions afforded by the bearings box; in short, it requires a plinth.

1. Cut out the plinth A, as shown on Plan 8. Now refer to Plan 1C, which shows the location of peg holes in the base of the bearings box. Cut the four pegs to fit. Drill four corresponding holes in the plinth A. Glue and insert the pegs, so that the two nearest the large holes in the plinth, to be used later on, protrude 5mm (3/16in) and the other two protrude 14mm (9/16in).
2. Cut out the linkage bar B, the coupler C, and the lever D. Drill holes, as indicated.
3. Cut out the base E for the pivot block F. Locate and drill holes for the two dowel pegs, which are cut to length. These fit into plinth A, as shown by the dotted lines.
4. Cut out pivot block F, and drill a hole to receive the block pin I. Now cut out the recess in the block. Glue this to its base E, as shown on the plan. They can now be glued into the block E.

Four-bar linkage consists of four links connected by pin joints. Rotation of the crank is translated into an oscillating movement of the lever, by means of the coupler bar that connects them.

FAR RIGHT: The crank's action turns into an ellipse where the linkage bar meets the coupler. It then turns into an arc, where the coupler joins the lever.



PLAN 8
Making the four-bar linkage mechanism. A: plinth; B: linkage bar; C: coupler; D: lever; E: base for pivot block; F: pivot block; G: dowel collets; H: dowel spindles; I: block pin; J: dowel pin; K: dowel collet; L: crank pin wheel. (See plan 4 for the peg board and pegs.)

5. Cut six dowel collets G and two dowel spindles H. Cut a longer dowel for the block pin I.
6. Cut the crank pin dowel J, the dowel collet K, and the wheel itself L.
7. To assemble the mechanism, slot the pivot block E/F into the plinth A, as shown, with the two fixed pegs. Insert the crankshaft through the bearings box and fix the crank pin J/L to its end. Press the bearings box on to the pegs in the plinth A.
8. Refer to Plan 4C. The crank slider peg board and pegs are essential to the operation of the four-bar linkage. This should have been cut and drilled already if you are working, in sequence, through the mechanisms. Fix the peg board, by the glued-in pegs, into the outer holes in the side of the bearings box.
9. Assemble the three bars B, C and D. The linkage bar B is fixed under the coupler D, loosely locked by a spindle H and two collets G. The lever D attaches likewise to the other end of the coupler C. Glue the collets to the spindles but ensure that the three-pieced mechanism works freely within the joints.
10. Fix the free end of the linkage bar B on to the crank pin J/L. Place the two-headed dowel pins into the peg board (made from Plan 4), to govern the linkage bar B.
11. Insert the free end of the lever D into the pivot block F, passing the block pin I through and securing with dowel collets K. Leave one of these unglued, so that the mechanism can be dismantled.

The bell crank linkage alters an up-and-down motion into a side-to-side motion. This is achieved by the L-shaped component joining the linkage bar to the lever, at the top.

The horizontal, push-pull action of the lever, at the top, moves 25mm (1in) on this model.

COLOUR AND NUMBER THE PARTS

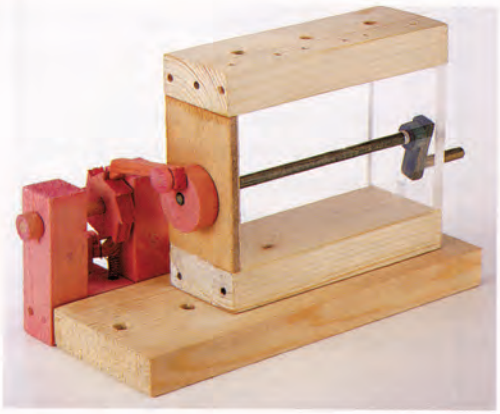
The Bell Crank

This linkage is actually a kind of lever. If the L-shaped component is extended, in either direction, the movement achieved gives greater leverage. This can also be done by moving the position of the fulcrum; some patient experimentation should bring about satisfying results when incorporating this linkage into a piece. One action the movement seems to evoke is that of a woodpecker.

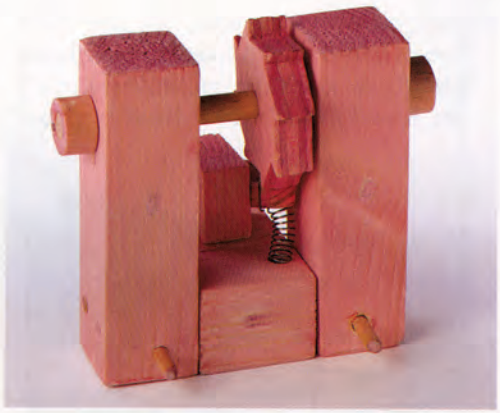
Making the Bell Crank

1. Cut the lever support block A, from 13/16in (20mm) batten, and drill a hole, as indicated on Plan 9, to a depth of 16mm (5/8in).
2. Cut out the extension block D. Drill a hole to match the hole in the lever support block A, to a depth of 17mm (11/16in).
3. Cut the thick dowel pin C to fit into both these holes. Glue it into the lever support block A.

The ratchet is a notched wheel, enabling movement to be effected in one direction only. This is achieved by a driving pawl pushing the ratchet wheel forward and a supplementary pawl checking it from slipping back.



The ratchet block assembly shows the supplementary pawl, supported by a spring, engaging the ratchet wheel. This moves forward one notch per revolution.



ABOVE: Detail showing how the supplementary pawl is positioned on the block. The spring is super-glued into holes in the block and the underside of the pawl.

The driving pawl, the crank pin and the dowel collet, which locks it in position.

13. Insert the lever support block A, and its fixed dowel pin C, into the extension block D. Place the lever A on top and operate.

COLOUR AND NUMBER THE PARTS

RATCHETS

The ratchet supplies movement that is not continuous and can give a piece more time in which to complete a cycle. This intermittent, or stepped motion is governed by the number of teeth on the ratchet wheel.

On this model there are eight teeth on the wheel. In order to complete the whole cycle, the crank needs to be turned eight times, with one revolution moving the ratchet wheel forward one notch. At, say, a second at a time, one cycle takes eight seconds.

The ratchet mechanism is governed by a long arm, the driving pawl, which turns on the crank pin, pushing the notched wheel forward. Below the wheel is a shorter arm, the supplementary pawl, which ensures that the wheel stops at the right place, correctly positioned for each push of the driving pawl.

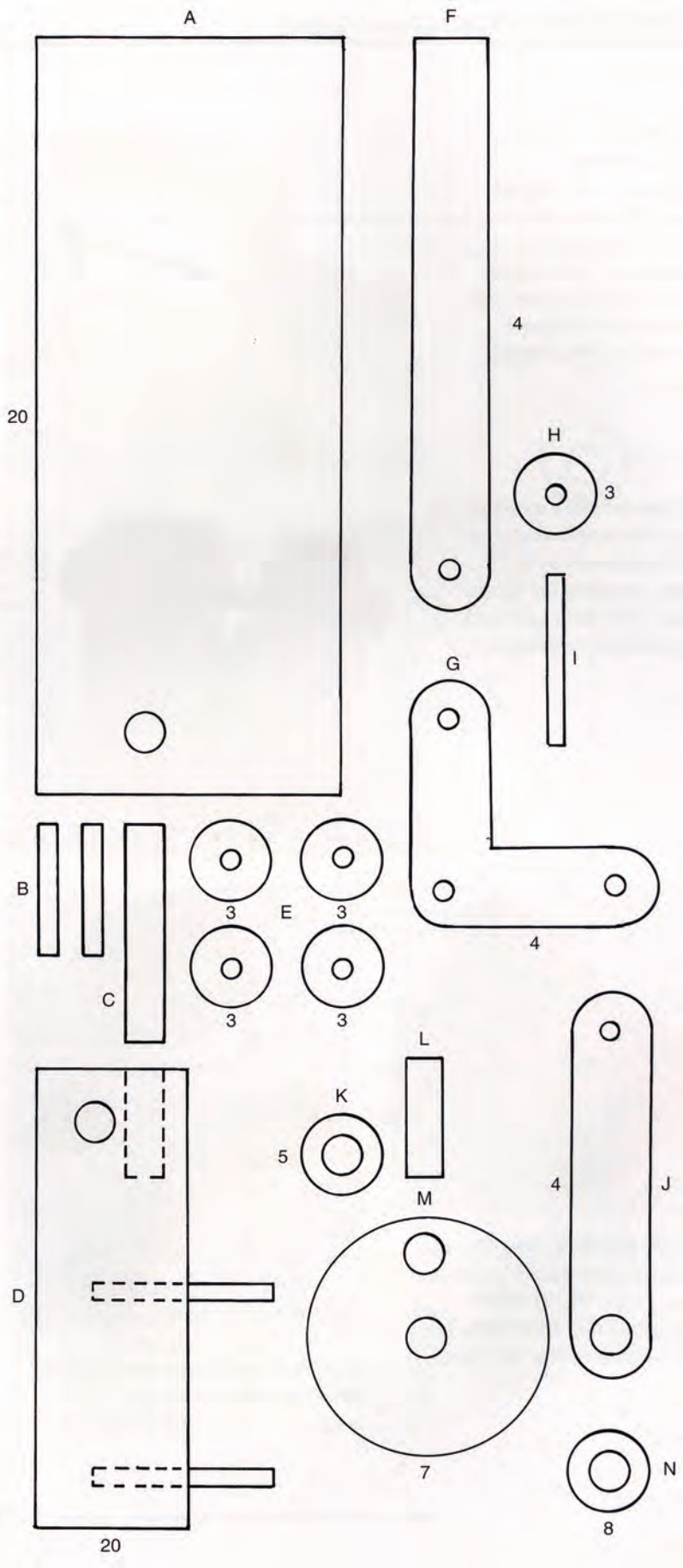
Making the Ratchet Assembly

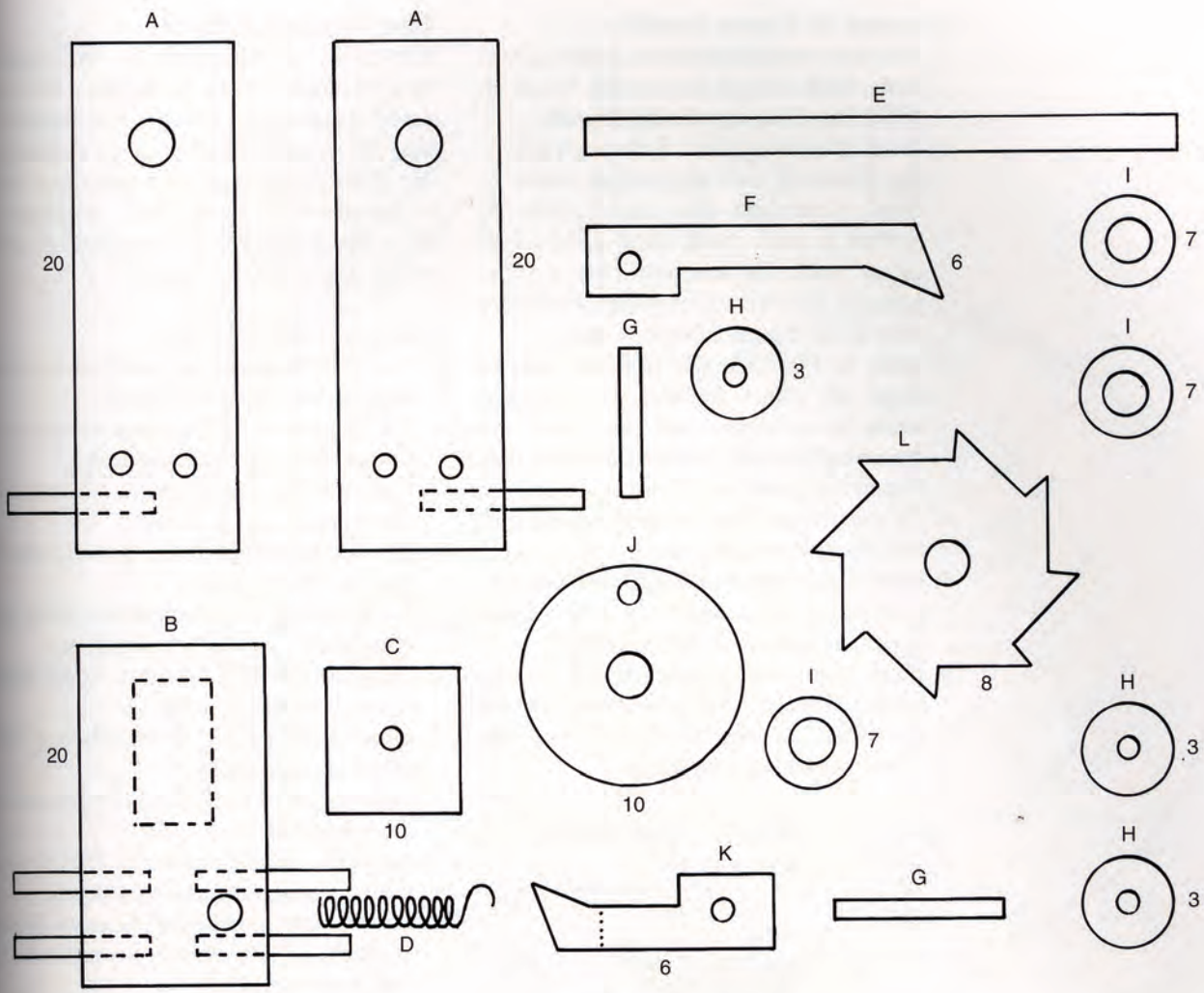
1. Cut out two pillars A, and drill holes in them, as indicated on Plan 10. Drill holes in their sides, centrally positioned, to receive two cut 3mm (⅛in) dowels. Glue these in.
2. Cut out the ratchet block B/C. Drill a shallow – 3mm (⅛in) – hole in block B, for the spring D. The exact diameter must be determined by the size of spring inserted.
3. Drill holes in the sides of block B to match the holes you cut in the pillars A. Cut and insert 3mm (⅛in) dowel pins to fit them.

PLAN 9

Making the bell crank. A: lever support block; B: dowel spindles; C: dowel pin; D: extension block; E: dowel collets; F: lever; G: L-shaped arm; H/I: pivot pin; J: linkage bar; K: dowel collet; L/M: crank pin; N: washer.

4. Cut two thin dowel pins to fit holes that you now drill into the side of the extension block D.
5. Cut out the lever F, and drill a hole, as shown, in one end. Cut out the L-shaped arm G, drilling three holes where indicated. Now cut the linkage bar J, drilling a small and larger hole.
6. Cut out the dowel spindles B, and four dowel collets E.
7. To assemble the bell crank, place the linkage bar J over the bottom of the L-shaped arm G. Insert a dowel spindle D through the two holes and secure with two dowel collets E at either end.
8. Now do the same for the lever F, where it meets the top of the L-shaped arm G. Glue the two pairs of collets E to their spindles B, ensuring that the mechanism moves freely within the joints.
9. To attach the mechanism to the side panel of the bearings box, first insert the crankshaft and slip the washer N on to the end. Then fix the crank pin L/M next to the washer N.
10. Fix the linkage bar J on to the crank pin L/M, and friction fit the thick dowel collet K on to the pin.
11. Insert the pivot pin H/I through the centre hole of the L-shaped arm G, and halfway into the central hole in the top side of the bearings box. Centre the mechanism over the crank pin L/M. Pushing it right home will impair the movement.
12. Push the extension block D, with the fixed pins, into the base of the bearings box, where two holes are located on the side.





4. Drill a hole through the small block C, position it as indicated by the dotted line, and glue it on to block B.
5. Fit one end of the spring D into the shallow hole in block B. Fix it with superglue. Straighten out the other end of the spring D 10mm (⅜in) long with pliers.
6. Cut out the supplementary pawl K. Drill a narrow channel through it, as indicated by the dotted line. Also drill a hole in it for a dowel spindle G, cut to length.
7. Insert the 10mm (⅜in) straightened piece of wire at the end of the spring D through the narrow channel in the foot of the supplementary pawl K.
8. Cut a dowel spindle G. Insert it through block C, and the supplementary pawl K.
9. Cut two dowel collets H, glueing one end to the spindle G, and friction fitting the other end to lock the pawl K, in position.
10. Cut to length the dowel shaft E. Cut out the driving pawl F. Cut and drill two thick shaft collets I and a thin collet H.
11. Cut the crank and pin J/G, and lastly the ratchet wheel L.

PLAN 10
Making the ratchet assembly. A: pillars; B/C: ratchet block; D: spring; E: dowel shaft; F: driving pawl; G: dowel spindle; H: dowel collets; I: shaft collets; J/G: crank and pin; K: supplementary pawl; L: ratchet wheel. (See *Plan 8 for plinth.*)

Arranging the Ratchet Assembly

1. Slot the two pillars A on to the dowel pins, each side of the ratchet block B, which has been assembled already.
2. Insert the dowel shaft E through one of the pillars A, and the ratchet wheel L. Pass it through the other pillar A. Secure it with thick shaft collets I at either end. Ensure that the ratchet wheel is directly over the supplementary pawl K on the ratchet block, B/C.
3. Refer to Plan 8A, which shows how to make the plinth for the bearings box, which fits on to the plinth pegs. Insert the crankshaft into the bearings box and friction fit the crank pin J/G on to the end.
4. Fit the driving pawl, loosely, on the pin. Secure with a shaft collet I.
5. Push the ratchet block B/C, with its two protruding pins, into the side of the plinth, as indicated on Plan 8A.
6. Place the driving pawl F on to the ratchet wheel L. Turn the crank handle clockwise or anti-clockwise, but the wheel will only go forwards.

COLOUR AND NUMBER THE PARTS

The Geneva Wheel, while not strictly a ratchet, does provide intermittent, or stepped motion. Unlike the ratchet, the wheel can turn in either direction, but without the ratchet's locking mechanism. It is shown here without its shield, which can be seen on the plan.

The Geneva Wheel

Known by watchmakers as the Geneva Stop, this mechanism works like a film projector, stepping the film on, one frame at a time. The crank pin enters each channel, or slot, at every full turn, so it takes four turns to complete the cycle. The advantage of this is that it provides a long pause, or dwell period between each event.

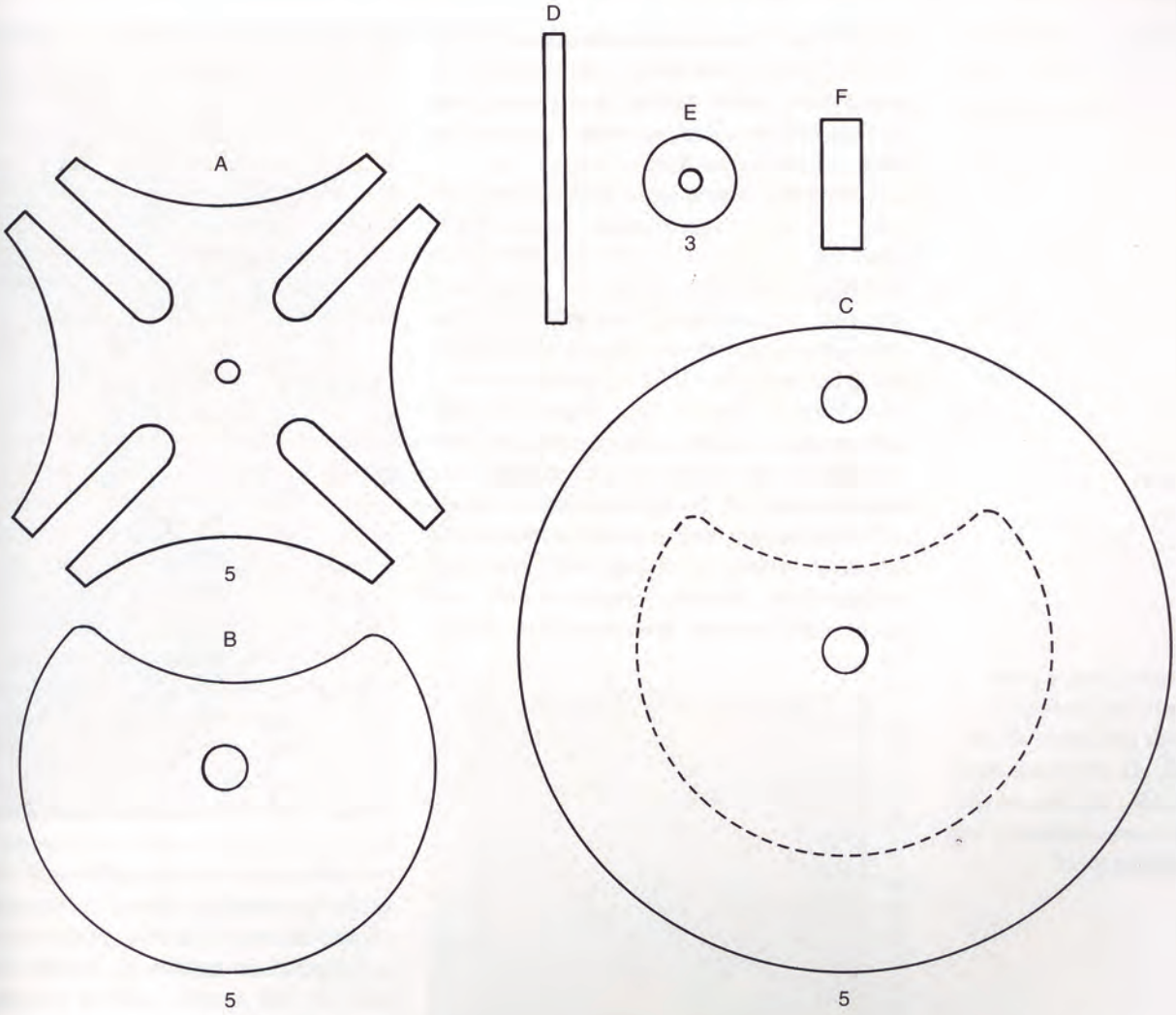
Making the Geneva Wheel

1. Cut out the cross A, and drill a central hole, as indicated on Plan 11.
2. Cut the shield B (shown on the plan as a dotted line), and drill the hole.
3. Cut out the crank wheel C, and drill two holes.
4. Cut the dowel pin D, the dowel collet E, and the dowel pin F.
5. To assemble the mechanism, insert the crankshaft into the bearings box.
6. Glue the shield B on to the crank wheel C, so that the holes line up.
7. Glue the dowel pin F into the top hole in the crank wheel C.
8. Glue the dowel collet E on to the end of the spindle D.
9. Insert the spindle and collet D/E through the hole in the cross A, to friction fit.
10. Insert the assembled Geneva Wheel into the middle hole in the top, side, of the bearings box.
11. Locate the pin F of the crank wheel into one of the four slots, or channels, in the cross A.
12. Operate either clockwise or anti-clockwise and the Geneva Wheel will turn in the opposite direction.

COLOUR AND NUMBER THE PARTS

DRIVES

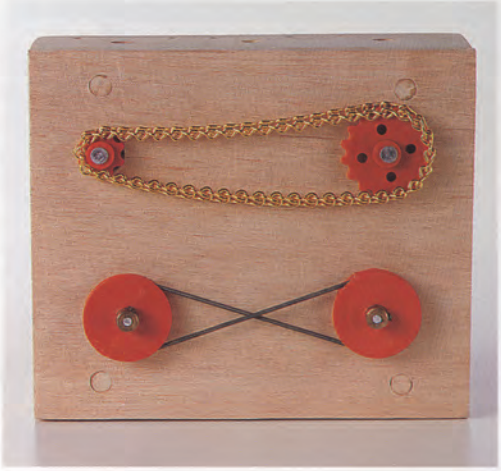
The standards and tolerances found in 'grown-up' engineering do not apply to most modern automatists. Their work,



while being highly creative and inspirational is, for the most part, uncomplicated, providing pretty basic mechanical movements. With this low-tech approach in mind, it is possible to turn to the model shop to minimize the tedium of making certain component parts. Making your own pulleys and drive wheels from wood is simple enough, but the world of toothed drive belts and tensioning is beyond the scope of this book.

Positive and Friction Drives

There are two types of drive: positive and friction. A chain and sprocket system is positive, always in synchronization, because the



ABOVE: PLAN 11 Making the Geneva Wheel. A: cross; B: shield; C: crank wheel; D: dowel spindle; E: dowel collet; F: dowel pin.

Positive and friction drives are obtainable from model shops. They serve well enough, hidden inside a piece but, aesthetically, leave something to be desired.

teeth of the wheel are permanently locked into the links of the chain. Friction drive is a much freer affair, where there is slippage and, therefore, a less accurate transmission of the rotary connection.

The type of drive used depends on how exact the performance needs to be. If it is vital for an action to be repeated with absolute regularity, then a chain and sprocket system should be used. If, on the other hand, it does not much matter that the drive band slips a little, losing accuracy, then friction drive is the way to go. One advantage of friction drive is that the flexible metal drive band can be crossed over and the action of the driven wheel reversed.

Whether you use a positive chain and sprocket system, or a friction drive band with pulleys, you may need to calculate speed differences between the driven wheel and the driver. With pulleys, use the diameter of the wheels; with the sprocket system, count the number of teeth. For instance, in the example here, the number of teeth on the driver sprocket is eight, and the driven sprocket has sixteen. Since the pulleys for the friction drive band are of the same size they will, naturally, rotate at the same speed. If they are twisted, they will turn in opposite directions.

The small pinion wheel has half the number of teeth as the larger, driven wheel. As the pinion turns clockwise, the larger wheel rotates anti-clockwise, and at half the speed.

An alternative, effective and easier method of making cogwheels is to use wooden struts. These are glued, sandwiched between two discs.

GEARS

Gear wheels are really like little levers, meshed, to provide continuous action. They allow some components to move more slowly, or faster and more powerfully than others. As with drive wheels, this can be achieved by either the positive method, locking the cogs into each other, or by friction discs, with gravity supplying the magic.

Making simple automata and mechanical toys involves only the most modest of gearing methods, whether they use tooth-driven wheels or friction-driven discs. Gears, like chain and sprocket wheels and pulleys, can be bought from model shops; while they work very efficiently, they are rather unlovely to behold, so tuck them away well out of sight if you do use them.

Wooden cut cogwheels are another matter. All that precise cutting can be justifiably flaunted. Many modern automatists, unlike their predecessors, like to show the workings and reveal the magic. On the other hand, not all pieces lend themselves to this approach and there is something to be said for hiding the mechanics, especially if you believe that, by revealing them, you diminish the wizardry. Each maker needs to decide whether to be a magician or engineer. Or both.

Making Cogwheels

Make the painstaking cutting of wooden cogwheels much easier by laying out wooden struts, evenly spaced, on a disc covered by another disc, and glueing them

Detail of the simple construction of the strutted cogwheel.

together. The action is the same for both methods, which require careful testing of the relative positions of the bearings. Ensure that both wheels move easily, forwards and backwards.

Making Gearwheels

1. To make the strutted wheels, cut and drill two small discs A, as indicated on Plan 12 (*see* page 102).
2. Cut eight small struts B to size, and glue on to the small disc A.
3. Cut and drill two large discs C.
4. Cut 16 struts to size and glue in position on the large disc C, as shown.
5. Glue disc A on to small strut B, inserting a rivet F through the two small discs A.
6. Glue disc C on to the large struts D, inserting a rivet F through the two large discs C.
7. To make the cogwheels G and H, cut out and drill as shown on the plan.
8. Insert the two rivets F, with washers E between the work and the wheels.
9. Cut a plywood backboard 127 × 108 × 5mm (5 × 4¼ × 3/16in). Position the wheels as on the plan.

COLOUR AND NUMBER THE PARTS

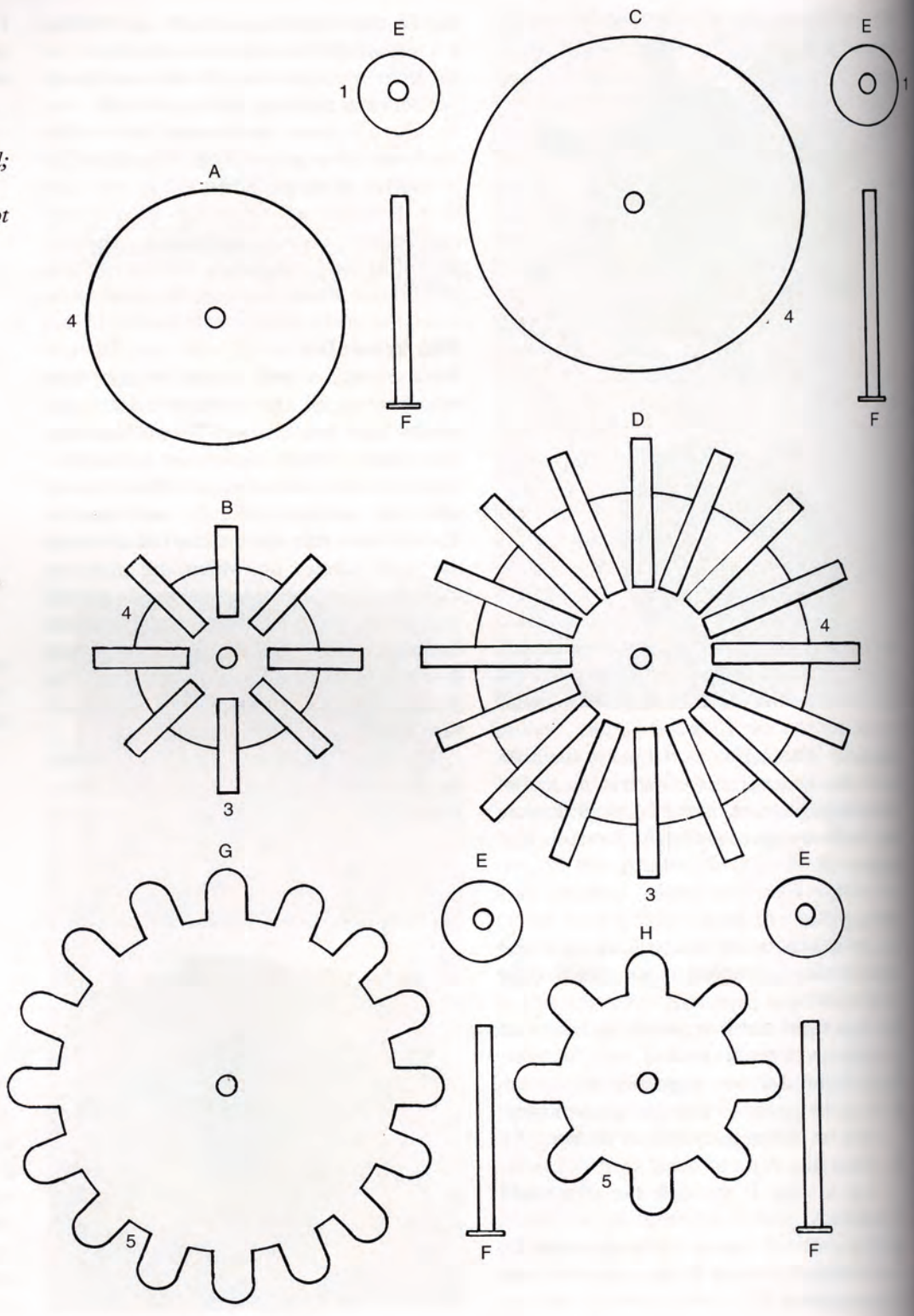
Pin Wheels

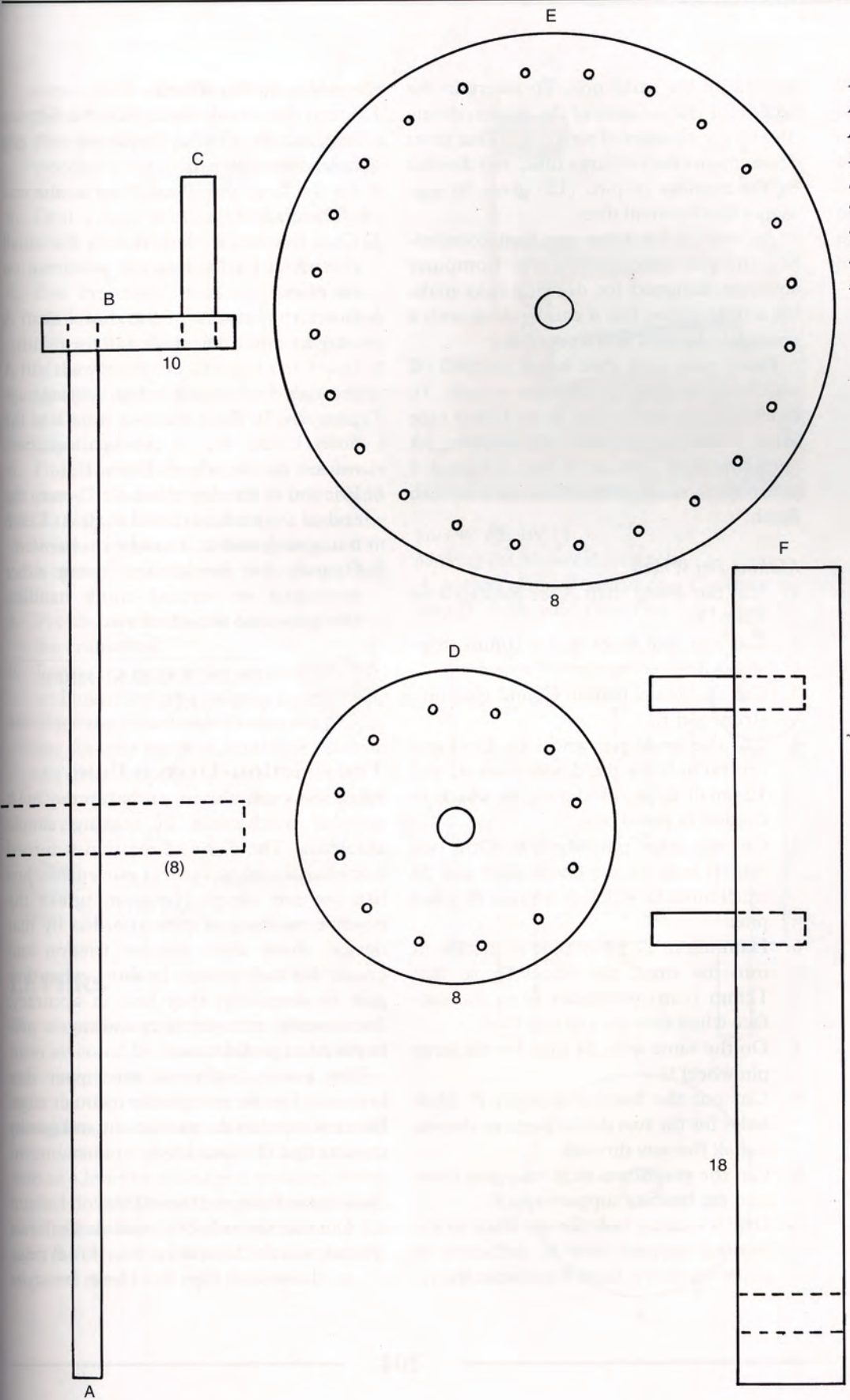
To construct a pair of pin wheels, first draw two circles, the size to be determined by the ratio you choose. To use the ratio shown here, which is two to one, draw circles with a two to one ratio in their diameters, for example, 80mm and 40mm. These measurements are the diameters of the pitch circles on which the pins are located. The perimeter should extend beyond the pitch circles, to accommodate the pins, with a 7mm strip for the larger disc and 6mm strip for the small disc. The diameters of the cut circles will now measure 94mm and 52mm, respectively.

The pitch circles are divided up so that the number of pins are in the same ratio. Here, there are 24 pins on the large disc

Pin wheels give a positive drive in both directions, serving as surrogate bevel gears. The two wheels mesh at an angle of 45 degrees, so that the rotary plane is changed from vertical to horizontal, or vice versa.

PLAN 12
Making gearwheels.
A: small disc; B: small struts; C: large disc; D: large struts; E: washer; F: rivet; G: large cogwheel; H: small pinion wheel; I: plywood backboard (not illustrated) 127 × 108 × 5mm (5 × 4¼ × 3/16in).





PLAN 13
*Making pin wheels. A: dowel shaft; B: stripwood; C: dowel handle; D: small pin wheel; E: large pin wheel; F: bearing support arm. (*See *Plan 8 for plinth.)*

and 12 on the small one. To ascertain the angles for the division of the circles, divide 360 by the number of pins (24). That gives 15 segments for the large disc; 360 divided by the number of pins (12) gives 30 segments for the small disc.

As long as the ratios are kept compatible, the pin wheels will work. Computer software designed for drawing may make life a little easier, but it can be done with a compass, dividers and a protractor.

Panel pins, with their heads snipped off and filed, are used for the pin wheels. To mark the pins for cutting, wrap 12mm tape around them as a guide for snipping. A spirit marking pen could also be used if you wish to sand off the heads to a smooth finish.

Making Pin Wheels

1. Cut the dowel shaft A, as indicated on Plan 13.
2. Cut and drill holes in 5 × 10mm stripwood B.
3. Cut the dowel handle C, and glue into stripwood B.
4. Cut the small pin wheel D. Drill one central hole for the dowel shaft A, and 12 small holes, as shown, in which to friction fit panel pins.
5. Cut the large pin wheel E. Drill one central hole for the crank shaft and 24 small holes in which to friction fit panel pins.
6. Hammer in 12 panel pins to friction fit into the small pin wheel D, so that 12mm (½in) protrudes from the surface when they are cut and filed.
7. Do the same with 24 pins for the large pin wheel E.
8. Cut out the bearing support F. Drill holes for the two dowel pegs, as shown, not all the way through.
9. Cut the two dowel pegs and glue them into the bearing support arm F.
10. Drill a bearing hole for the shaft in the bearing support arm F, sufficient to allow the dowel shaft B to rotate freely.

Assembling the Pin Wheels

1. Insert the crank shaft into the bearing box, and fit it on to the plinth, with peg holes, from Plan 8.
2. Fit the large pin wheel E on to the end of the crankshaft.
3. Glue the dowel shaft A into the small pin wheel D, halfway up, as shown on the plan.
4. Insert the bottom of the dowel shaft A into the outer hole drilled in the plinth.
5. Insert the top end of the dowel shaft A through the bearing in the bearing support arm F. Press the two pegs into the holes in the top of the bearings box, nearest the pin wheels D and E.
6. Friction fit the dowel handle C on to the end of the vertical dowel shaft A. Leave it unglued, so that it can be dismantled.
7. Operate the mechanism, using either horizontal or vertical crank handles, clockwise and anti-clockwise.

COLOUR AND NUMBER THE PARTS

The Friction-Driven Pole

After the cam, this is probably the most popular mechanism in making simple automata. The plane of rotation is turned from horizontal to vertical movement, just like the pin wheel. However, unlike the positive meshing of pins afforded by that device, these discs rely on friction and gravity for their power. In short, what they gain in simplicity, they lose in accuracy. Fortunately, accuracy is not always a prerequisite of performance.

The lower disc turns the upper disc because of its location under its outer edge. Friction supplies the movement and gravity ensures that the discs stay in contact.

Making the Friction-Driven Pole

1. Cut out the support block A. Drill two holes in the base to receive dowel pegs, as shown on Plan 8. These must be

compatible with the two holes in the plinth on Plan 8.

2. Cut the dowel pole D. Fix and glue a wooden bead to the top, widening the hole as necessary.
3. Drill a hole in the top of the support block A, to receive the dowel pole D, so that it can easily rotate in the hole.
4. Cut the dowel pegs and insert them into the support block A, as shown. Ensure that these will fit into the holes in the plinth, from Plan 8.
5. Cut the driver disc B, and drill a central hole to receive the dowel pole D. Glue in place.
6. Glue the driven disc C to the lower part of the dowel pole D, as indicated.
7. To assemble the mechanism, insert the crankshaft into the bearings box and fit it on to the plinth with pegs (from Plan 8).
8. Fix the driver disc B on to the end of the crankshaft.
9. Locate the pegs of the support block A, and insert into the holes in the plinth.
10. Place the dowel pole D into the hole in the support block A, so that it rests on the driver disc B.
11. Operate the mechanism in either direction.

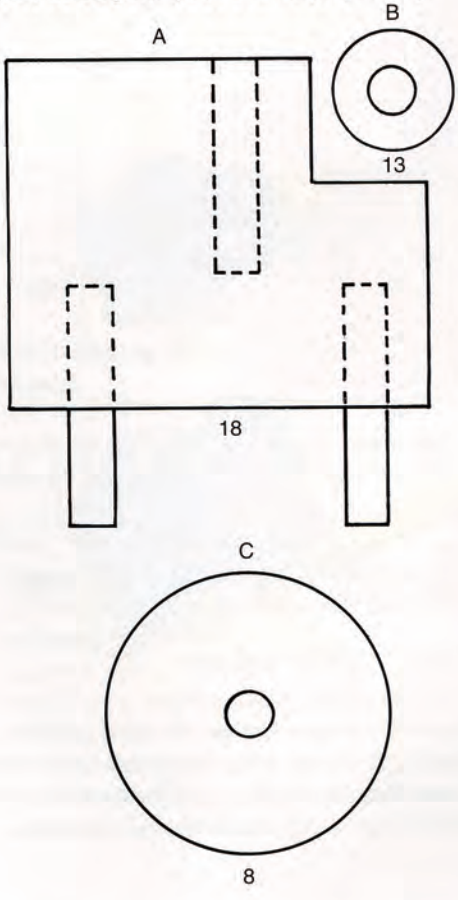
COLOUR AND NUMBER THE PARTS

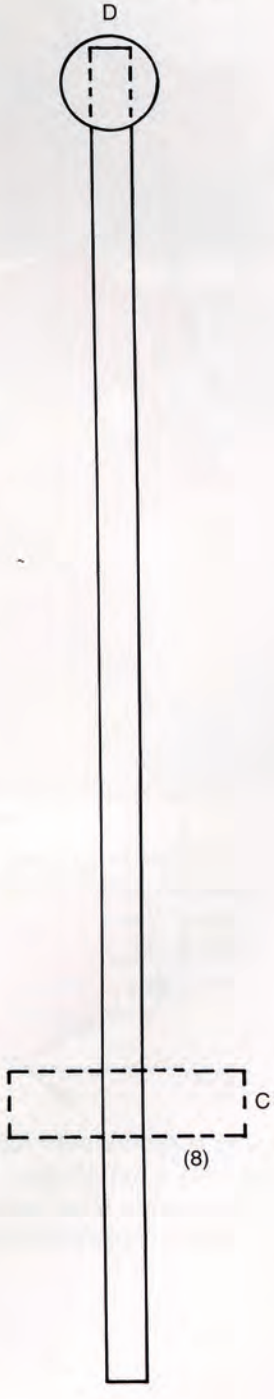
LEVERS

The lever was probably the first mechanism invented by man. Although the wheel may have been accorded greater importance in the subsequent development of machinery, it almost certainly owes its invention to a prehistoric being using a club as a lever to dislodge a boulder, which hurtled downhill and thus planted the idea. Later generations added refinements to the axle, developed spokes and, subsequently, cogs and cams, and even hubcaps.

The friction-driven pole performs the same action as the pin wheel, but with half the complexity, and accuracy. It relies on friction and gravity to rotate, rather than the positive meshing of pins.

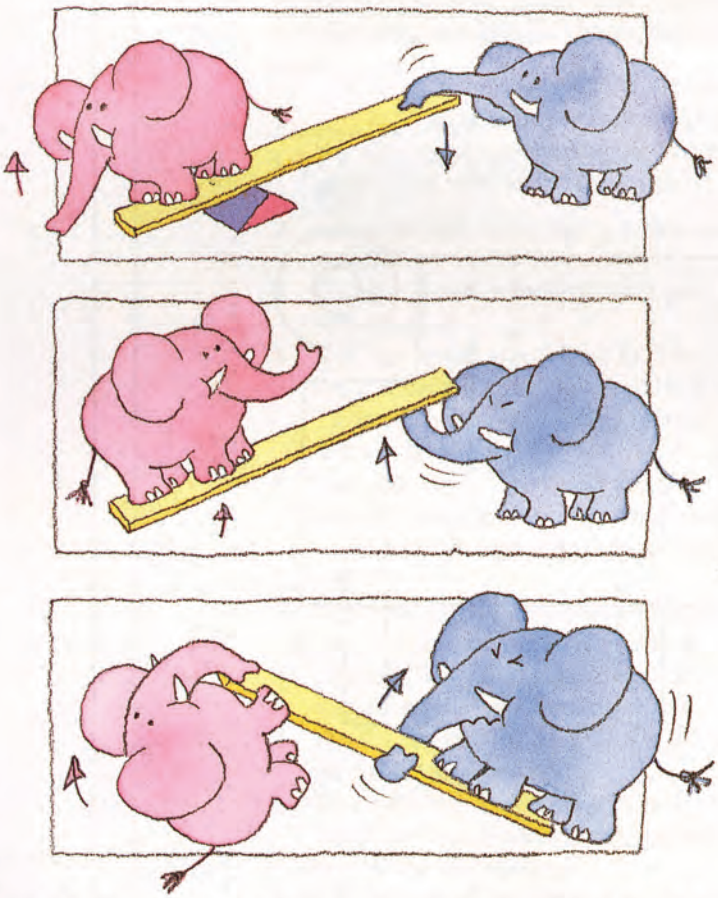
BELOW: *PLAN 14*
Making the friction-driven pole.
A: support block; B: driver disc; C: driven disc; D: dowel pole. (See *Plan 8 for plinth.*)





As the crankshaft turns, the crank pin lifts and drops the lever through a small arc.

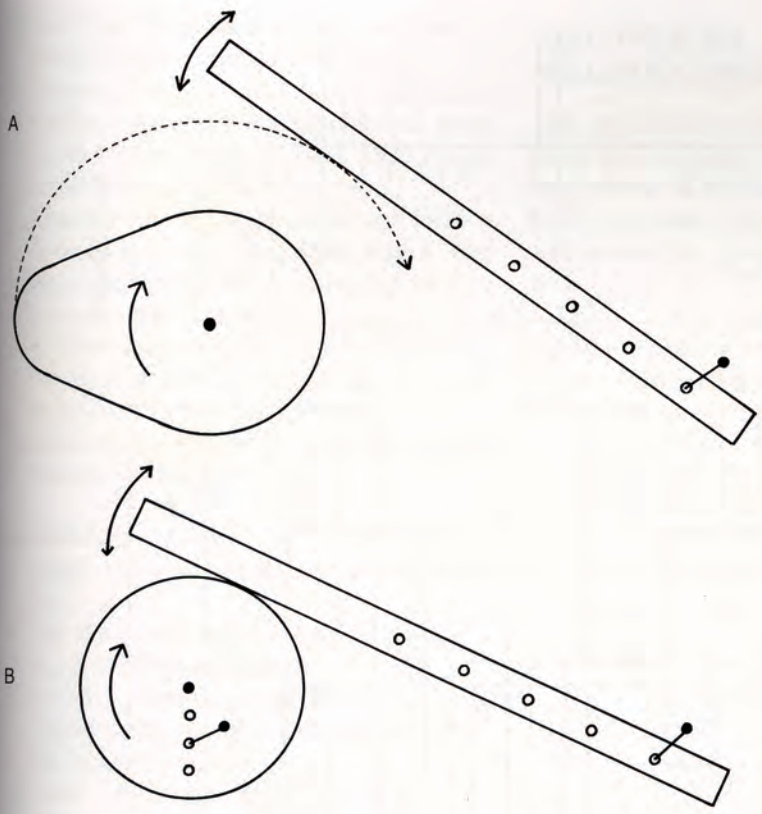
FAR RIGHT: If the motion is too fast, the lever could fly off the crank pin unless it is locked by a pivot block, as it is here.



A lever of the first order has the fulcrum located between the effort and the load, as in a pair of pliers. A lever of the second order has the load between the fulcrum and the effort, as in a wheelbarrow. A lever of the third order has the effort applied between the fulcrum and the load. Tweezers are an example.

There is a great deal of theory pertaining to levers, but much of it has limited relevance to the building of automata. The best approach for a maker of automata is to keep it simple. (For those who wish to delve deeper, there are many books on the subject.) A basic acquaintance with the lever and its functions is necessary, however; the 'Elephants' Effort' illustrations left should serve to explain the three classes of lever. The pink elephants are the loads. The blue elephants supply the effort. The fulcrums are the pivot points upon which the plank rests.

It was Archimedes ('Give me a fulcrum on which to rest and I will move the earth!') who devised the system of dividing levers into three different orders. All levers fall into the three classes. They can be used separately, like a spanner; in pairs, like scissors; or connected together, like lazy tongs. They can even be used in multiples, as in the teeth of a cogwheel, which are really a series of tiny levers lifting other levers. Most levers fall into the first and second classes, because they give a mechanical advantage, moving a *large load* using *small effort*. The third type is more unusual because its mechanical advantage is negligible. Indeed, the force needed to use it is greater than the force it can move.



ABOVE: Testing levers can be simply done by using cut-out card and pins. A shows a pear-shaped cam, which produces much the same performance for the lever as B, the eccentric disc, does for its lever. By experimenting with the pin holes, you can quickly and cheaply test the best positions for your mechanism.

ABOVE RIGHT: The slotted lever's positive contact with the crank pin does not depend on gravity, but moves within its restricted channel.

Restricted and Unrestricted Levers

The essential thing to remember when making levers is to construct their pivot points so that when the piece is moved or handled, the levers do not fall out of position. If you are using a pivot block in which to house the lever, ensure that the slot is deep enough to allow freedom of action, but not so deep that it does not act as a stop to prevent the lever from flying off the crank pin.

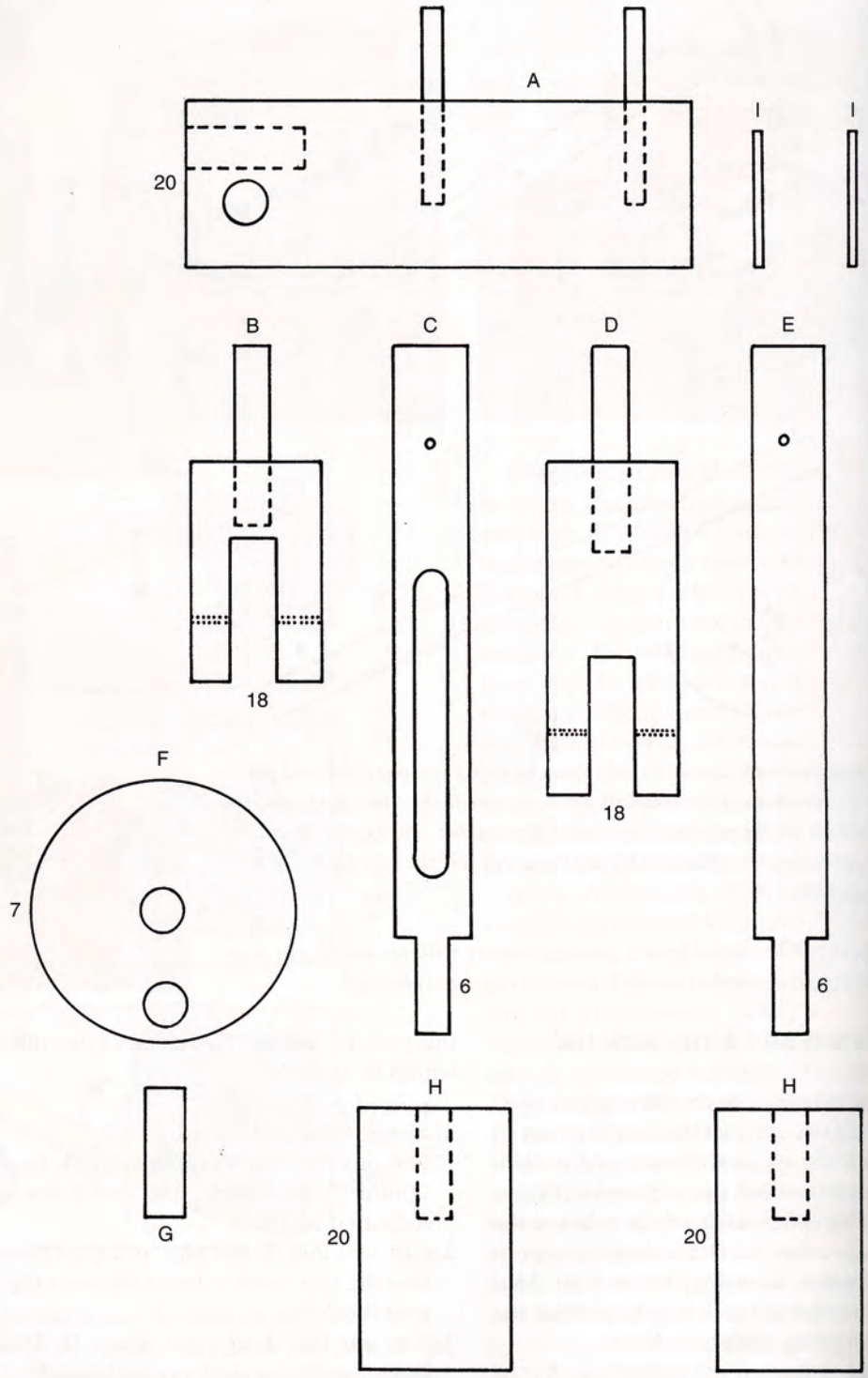
The advantage of the restricted, slotted lever is that, with or without a pivot block, the path of the lever is always controlled within its channel.

Making Slotted and Plain Levers

1. Cut out the lever support block A, from 20mm (13/16in) batten, and drill holes as indicated on Plan 15.
2. Cut two thin dowel pins and glue these into the two small holes in the lever support block A.
3. Cut out the short pivot block B. Drill holes for the support peg and spindle I. Cut out the slot for the lever.

The performance is similar to the crankshaft's string-operated 'nodding donkey', although here it is driven within its restricted limit.

PLAN 15
Making slotted and plain levers. A: lever support block; B: short pivot block; C: slotted lever; D: tall pivot block; E: plain lever; F/G: crank and pin; H: blocks; I: spindles.



4. Cut the dowel support peg and glue it into the hole in the support block A.
5. Repeat Step 3 for the tall pivot block D.
6. Cut out the slot first in the slotted lever C, and then the lever itself. Drill a hole to receive the spindle I.
7. Cut out the plain lever E, and drill a hole in it for the spindle I, which you now cut from 1/16in (1.6mm) piano wire (or use a panel pin).
8. Cut out and drill the crank and pin F/G. Insert and glue the dowel pin into the outer hole in the crank wheel.
9. Cut out the blocks H, drilling holes to receive the ends of the levers C and E.

Assembling the Levers

1. Insert the crankshaft into the bearings box.
2. Fix the crank and pin F/G on to the end of the crankshaft.
3. Fit the lever support block A dowel pins into the side of the bearings box base.
4. Insert the short pivot block B dowel peg into the hole in the lever support block A.
5. Secure the slotted lever C by inserting a spindle J into the walls of the short pivot block B, so that the slotted lever C is held between them, moving freely on the pin.
6. Repeat Steps 3 and 4 for the tall pivot block D and plain lever E.
7. Fit the blocks H on to the ends of the levers C and E. Square pegs in round holes can make a good friction fit.
8. Operate the mechanism, either backwards or forwards, using the two types of lever.

COLOUR AND NUMBER THE PARTS

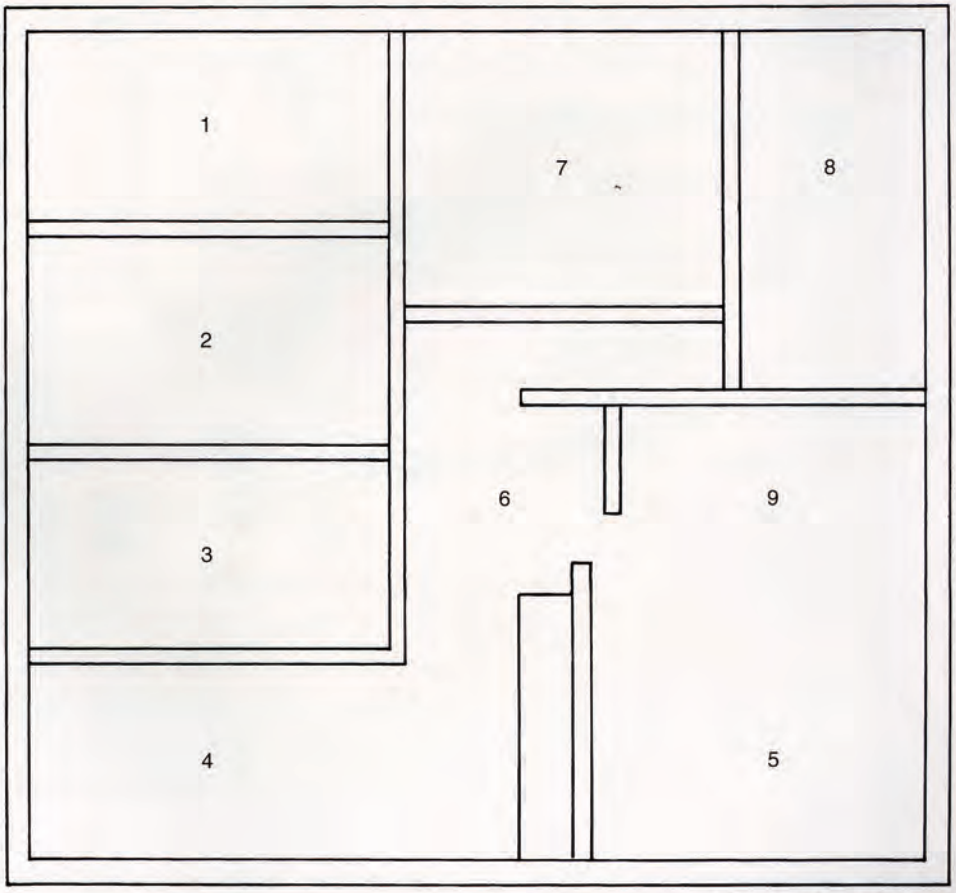
THE BOX OF MECHANISMS

The mechanisms and their component parts are contained within this box. The importance of keeping them in order cannot be stressed too much, and colouring and numbering each part is the best way to do it.

Making the Box of Mechanisms

1. Use 8mm plywood for the box and 5mm plywood for the interior sections.
2. Cut the lid and base of the box, 372 × 343mm (14⅝ × 13½in).
3. Cut the front and back panels, 372 × 70mm (14⅝ × 2¾in).
4. Cut the side panels 327 × 70mm (12⅞ × 2¾in).

Each component should be keyed with the number of the section to which it belongs. Every dowel, collet and washer should be marked and coloured to the specifications on the 'automata mechanisms boxed' chart (see *page 111*).



ONE-THIRD ACTUAL SIZE

Each component has an allotted section in the box, which is to be found on the 'automata mechanisms boxed' chart (see opposite). In this way you can select whichever mechanism you wish and refer to the plan to which it belongs.

The Box of Mechanisms

Section	*Automata Mechanisms Boxed*	*Plan*	*Colour*
1	Double Crankshaft in 2 parts to fit into bearings box (Section 5). Dowel collet for end of shaft	5	Red
	The rest of the shaft and handle assembly	5	Blue
	Lever, block and pivot stand	6	Red
	Lever, block and pivot stand	6	Blue
2	4-bar linkage, comprising linkage bar, coupler and lever. Dowel collets and 2 spindles. Dowel collet for crank pin	8	Light brown
	Crank slider and 4-bar linkage peg board, with 2 fixed pins and two dowel pins with bead heads	4	Plain
	Crank pin, comprised of wheel and pin	All	Plain
	Bell crank and lever support block with 2 fixed pegs	9 and 15	Plain
	Crank slider, rod, circular bearing with peg, slotted bearings and 2 pegs. Block, washer and collet	4	Mauve
	Plain lever in pivot block	15	Brown
	Slotted lever in pivot block	15	Brown
3	5 cams for pin follower	2	Green
	5 cams for roller followers	2	Red
	Roller followers	3	Red
	Pin follower with block	3	Red
	Pin follower with block	3	Green
	2 pin followers with blocks	3	Plain
	2 disc followers	3	Plain
	Disc followers with restraining pin	3	Plain
	2 dowel pins with bead heads	3	Plain
	Perspex shield, or panel with fixed dowel pins	3	Plain
4	Plinth with location pegs for bearings box	8	Plain
	Crank handle and shaft with collet	1	Blue
	Friction-driven pole and driven disc	14	Yellow
5	Bearings box	1	Plain
	Backboard with pegs for bearings box	12	Plain
	Large and small cut gearwheels	12	Cerise
	Large and small strutted gearwheels	12	Dark blue
6	4-bar linkage pivot block and base with 2 dowel collets and spindle	8	Light Brown
	Small pin wheel shaft and handle	13	Light Yellow
	Friction-driven pole support block with 2 pegs and driver disc	14	Yellow
7	Bearings box backboard with pegs. Chain and sprocket wheels (from model shop). Drive band and pulleys	–	Plain
	Large pin wheel	13	Light Yellow
	Geneva wheel, comprised of large crank pin and shield, dowel spindle, collet and washer	11	Light Green
8	Ratchet assembly, comprised of 2 pillars with pegs, ratchet block and subsidiary panel with spring. Dowel shaft with 2 collets, driving pawl and 2 collets	10	Pink
	Linkage bar, lever, fixed bar with dowel pins, 2 dowel spindles and 4 collets. Collet for crank pin (crank pin itself is in Section 2)	–	Light brown
9	Bell crank, comprising lever, L-shaped arm with pivot pin and collet. Linkage bar with 2 spindles and 4 collets. Lever support block with peg. Dowel collet and washer	9	Blue
	Pin wheel bearing support arm with 2 pegs	13	Yellow

Miniature automata mechanisms: seven of these little mechanisms use drawback springs to operate the machinery. The actual size can be seen on the cutting guide on the plan (opposite).

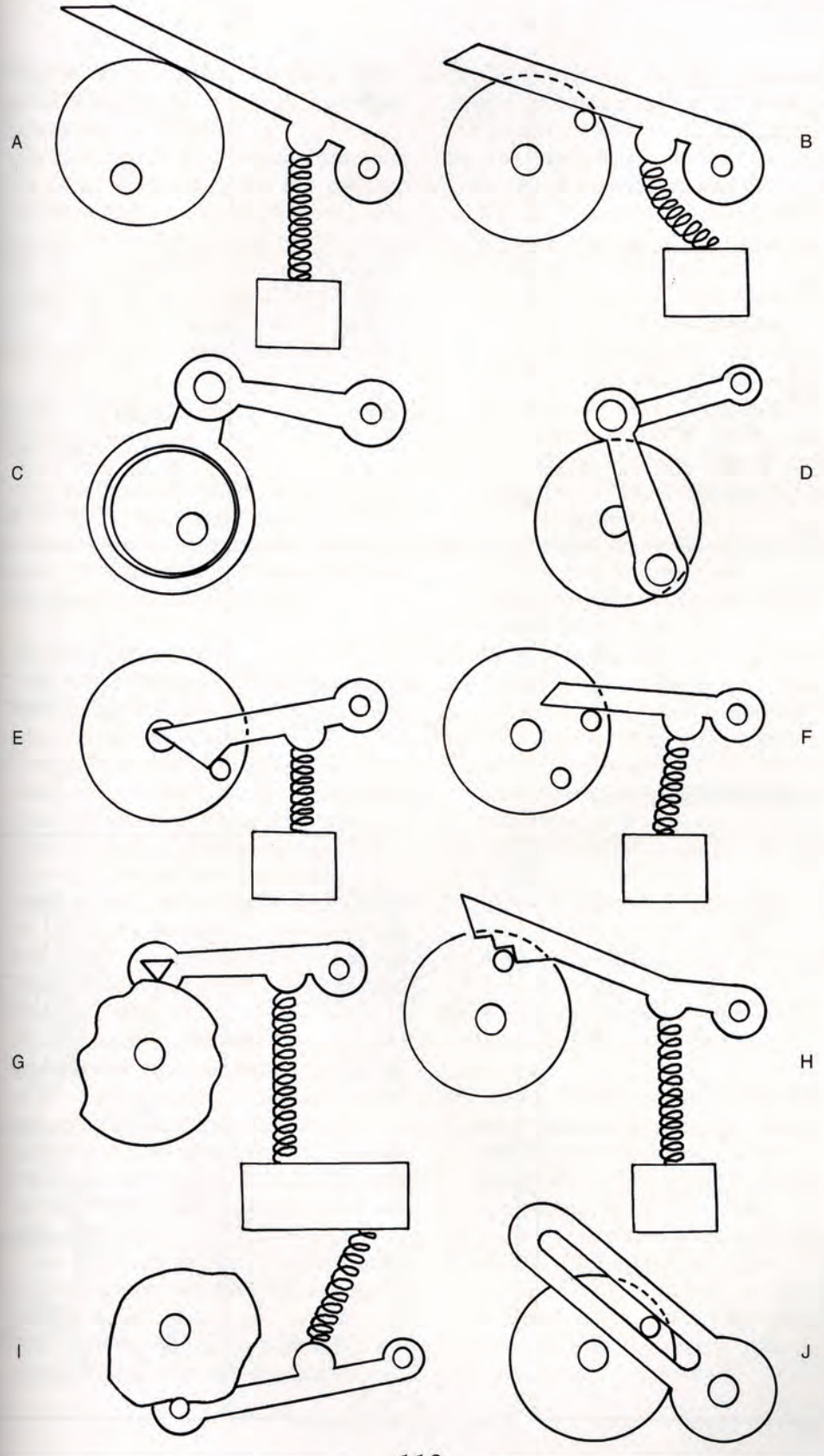
5. Glue and pin the box together, leaving the lid till the end.
6. Cut the walls for sections 1, 2 and 3, 145 × 64mm (5¾ × 2½in).
7. Cut the long retaining wall for sections 1, 2 and 3, 254 × 64mm (10 × 2½in).
8. Glue the walls of these sections, as in the diagram, to the box. You will have spaces between the sections of 78mm (3⅛in), 86mm (3⅜in) and 78mm (3⅛in). This leaves a space for section 4 of 72mm (2¹³⁄₁₆in).
9. Cut a wall for section 5, 112 × 64mm (4⅜ × 2½in) and a support block from a batten 105 × 47mm (4⅛ × 1⅞in).
10. Cut a wall for section 9, 157 × 64mm (6⅛ × 2½in) and a small section to support it, 47 × 64mm (1⅞ × 2½in).
11. Cut the wall between sections 6 and 7, 127 × 64mm (5 × 2½in). Cut out a rectangle, 44 × 51mm (1¾ × 2in), leaving 95mm (¾in) strip to glue to the long wall, supporting sections 1, 2 and 3.
12. Cut the last wall between sections 7 and 8, 143 × 64mm (5⅝ × 2½in).
13. Glue the remaining sections as on the diagram.
14. Attach the lid to the box, at the back, with a couple of brass hinges. (Butterfly hinges look nice.)
15. Fix two brass 'question-mark' latches to the edges of the lid at the front, with two little brass screws to hold them.
16. Finally, with the lid of the box securely fixed, the mechanisms should stay in their sections, even if the box is turned upside down.

MAKING MINIATURE MECHANISMS

All the mechanisms are cut from 6mm plywood and should be positioned in the box as shown on the cutter guide (*see* page 113). The shafts are flat-headed and round-headed rivet pins, secured at the back with 10 × 3mm (⅜ × ⅛in) stripwood blocks. Beads, 10mm (⅜in) in diameter, attached to rivet shafts at the back, serve as easy-to-turn knobs when viewed from the front. (If flat-headed rivets are not available, use nails instead.)

Making the Box

The box can be constructed in the same way as the larger box. The difference is that the base, containing the mechanisms, must be positioned in the middle, to allow the box to



PLAN 16
Miniature Mechanisms
A: eccentric disc with continuous movement; B: eccentric crank pin with continuous movement; C: eccentric disc with follower giving continuous movement; D: eccentric crank with connecting rod, giving continuous movement; E: eccentric crank pin with slow and sudden release of runner, giving intermittent movement; F: eccentric double crank pin with stepped and sudden release of the runner, giving intermittent movement; G: cam and runner with knife edge; H: crank pin and shaped runner giving a slow and 'nodding' release of the rūnner; I: cam and runner with pin; J: crank pin and slotted runner.

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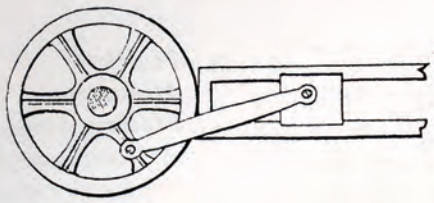

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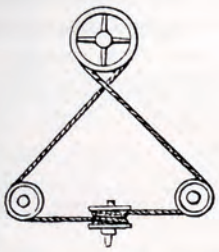

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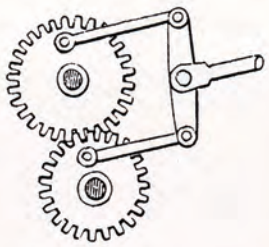

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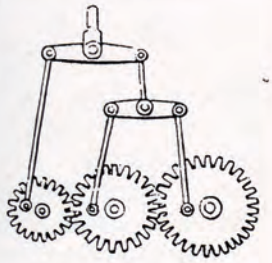

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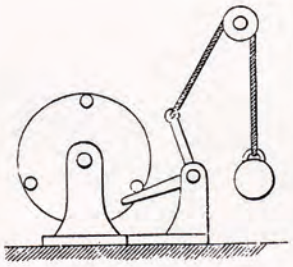

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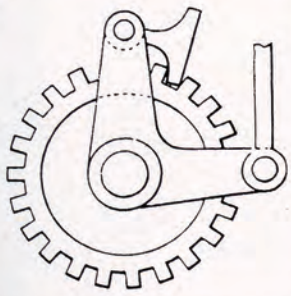

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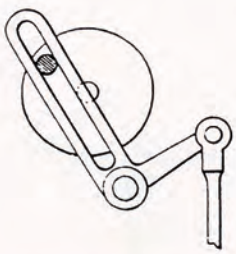

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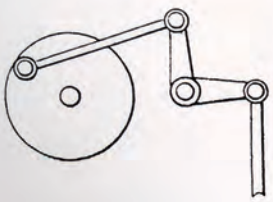

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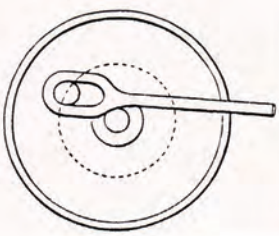

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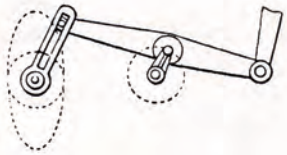

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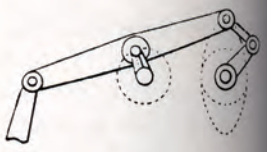

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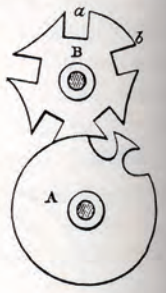

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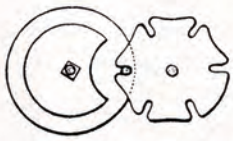

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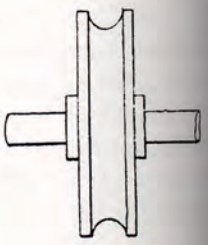

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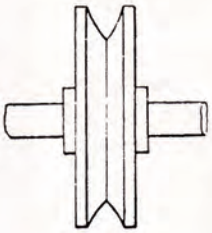

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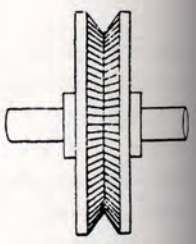

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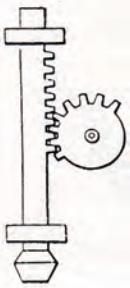

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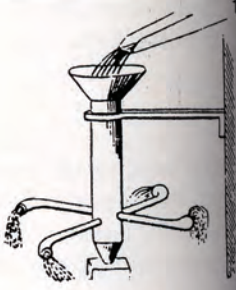

lie flat without touching the bead knobs. The lid must also be able to close without touching the mechanisms.

The dimensions of the box, made from 8mm (5/16in) pine, are 254 × 146 × 47mm (10 × 5¾ × 1⅞in) with the lid closed. The plan shows the actual size of the inside area. Fix two brass latches and screws to the lid at the front, and brass hinges at the back, to secure the lid to the box. The back is left open for easy operation of the knobs.

ADDITIONAL MECHANISMS

The nineteen mechanisms listed opposite and below, which are especially useful to the automatist, are taken from Henry T. Brown's *Five Hundred and Seven Mechanical Movements* published in 1868.

1. Ordinary crank motion.
2. A method of transmitting motion from a shaft at right-angles to another whose axis is in the same plane.
3. The rotation of the two spur gears, with crank pins attached, produces a variable alternating traverse of the horizontal bar.
4. A more complex modification of No.3.
5. Circular motion into alternating rectilinear motion, by the action of the studs on the rotary disc upon one end of the bell crank, the other end of which has attached to it a weighted cord passing over the pulley.
6. Reciprocating rectilinear motion into intermittent circular motion by means of the pawl attached to the bell crank, and operating in the toothed wheel.
7. Circular motion into variable alternating rectilinear motion, by the crank pin on the rotating disc working in the slot of the bell crank.
8. A modification of No.7, a connecting rod being substituted for the slot in the bell crank.
9. The rotation of the disc carrying the crank pin gives a to-and-fro motion to the connecting rod. The slot allows the rod to remain at rest at the termination of each stroke.
10. The slotted crank on the left is attached to the shaft, and the connecting rod that connects it with the reciprocating moving power has a pin that works in the slot of the crank. Between the first crank and the moving power is a shaft carrying a second crank, attached to the same connecting rod. While the first crank moves in a circular orbit, the pin at the end of the rod moves in an elliptical orbit, increasing the leverage of the main crank at those points most favourable for the transmission of power.
11. A modification of No.10, in which a link is used to attach the connecting rod to the main crank, dispensing with the slot shown in No.10.
12. By turning the shaft carrying the curved slotted arm, a rectilinear motion of variable velocity is given to the vertical bar.
13. The Geneva Stop, used in watches to limit the number of revolutions in winding up. The convex curved part a, b of the wheel B serves as the stop.
14. Another modification of the Geneva Stop.
15. A concave-grooved pulley for a round band.
16. A smooth-surfaced V-grooved pulley for a round band.
17. A V-grooved pulley with its groove notched to improve adhesion of the band.
18. Stamp. Vertical percussive falls derived from horizontal rotating shaft. The mutilated toothed pinion moves up the rack to raise the rod until its teeth leave the track and let the rod fall.
19. Barker's or reaction mill. Rotary motion of the central hollow shaft is obtained by the reaction of the water escaping at the ends of its arms. The rotation is in the reverse direction of the escape.

OPPOSITE PAGE:
Nineteen mechanisms especially useful to the automatist.